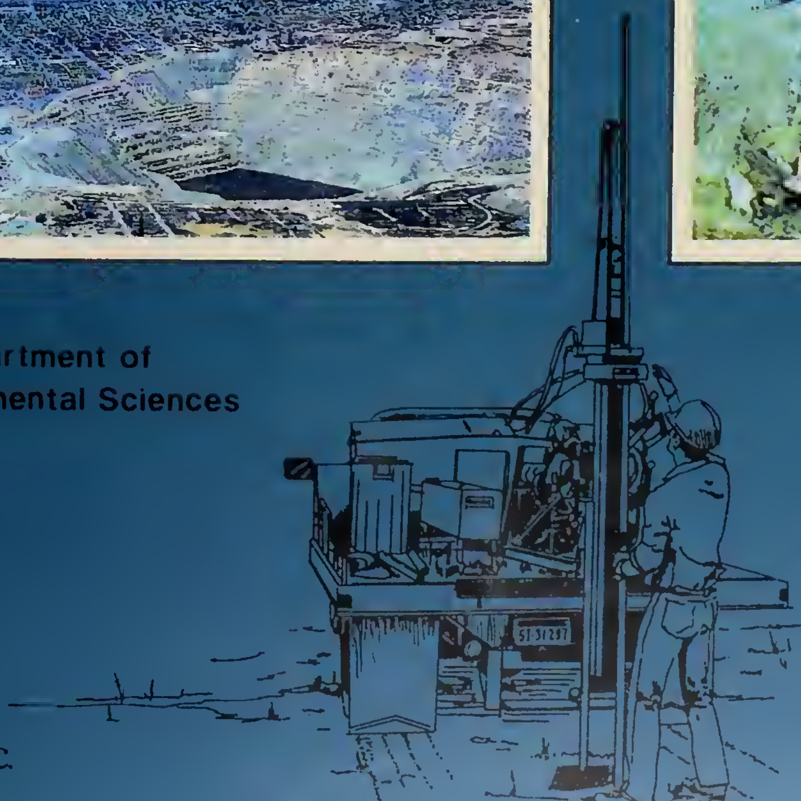
DRAFT FINAL
SILVER BOW CREEK CERCLA
PHASE II REMEDIAL INVESTIGATION
DATA SUMMARY

SILVER BOW COUNTY, MONTANA

AREA I OPERABLE UNIT



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REPORT

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Montana Department of
Health and Environmental Sciences

Prepared by:

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VOLUME I: TEXT

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EXECUTIVE SUMMARY

This report presents and summarizes results of environmental sampling completed during the Phase II Remedial Investigation at the Area I Operable Unit in and near Butte, Montana. The Area I Operable Unit is part of the larger Silver Bow Creek CERCLA (Superfund) site; the site was designated as an operable unit because types of contaminants and pathways of contaminant movement at the site are consistent and are somewhat unique with respect to surrounding areas.

Data produced during the Phase II Remedial Investigation supplement data generated during the Phase I Remedial Investigation at the site (MultiTech, 1987). The Phase II Remedial Investigation was completed in Area I to fill data gaps identified for the site prior to completing future studies and public health and environmental assessments.

The primary contaminants of concern in the Area I Operable Unit are metals, particularly copper, zinc, arsenic, cadmium, and lead. The primary pathways of contaminant movement in Area I include windborne transport, surface water runoff, infiltration of surface runoff into underlying groundwater systems, and groundwater movement to receiving surface water systems. The focus of this investigation was on identifying and characterizing sources of metals contaminants in the operable unit and in evaluating pathways of contaminant movement. The primary receptors of site contamination in Area I include inhabitants of the City of Butte and the environment. No effort was made during this investigation to identify receptors to site contaminants or potential impacts to receptors; these types of evaluations will be made during the public health and environment assessments for the operable unit.

General objectives to completing the Area I Operable Unit Phase II Remedial Investigation were to evaluate the following:

- Areas that may be sources of windblown dust which are contaminated with metals;
- The approximate areal and vertical extent of soil contamination;
- The nature and approximate extent of groundwater contamination and the pathways of contaminant movement in the area's shallow groundwater system;
- The source of relatively deep (greater than 150 feet) groundwater contamination in the upper Metro Storm Drain area.
- The impact of high flow on contaminant transport in the surface water system; and,
- The occurrence of organic compounds in the area's surface water system.

Other objectives to the investigation were to collect data to provide a basis for further characterization of the impact of exposed tailings/contaminated soils located within the operable unit on public health and the environment. Acquisition of these soils data were necessary to support a public health and environmental assessment of the operable unit and to evaluate various remedial alternatives for the area during future studies.

Three types of field investigations were performed during the Area I Operable Unit Phase II Remedial Investigation to fulfill project objectives. These include studies of surface water, groundwater, and tailings/contaminated soils. A direct evaluation of air in the operable unit was not performed during this investigation; this type of evaluation will be performed at a later date in conjunction with a city-wide air study. A brief description of the three studies completed during this investigation and a summary of results follows.

Surface Water

The surface water study performed as part of the Phase II Remedial Investigation focused on characterizing surface water quality and metal loads during a snowmelt runoff event which occurred in Butte during March, 1989. Sampling was completed during this in-bank runoff event at various sites within and adjacent to Butte; collected samples were analyzed for a variety of inorganic and organic parameters. In addition, a baseflow sampling event was completed at selected sites in Area I during August, 1989; samples collected during this sampling event were analyzed for organic compounds only.

Snowmelt sampling was completed to supplement limited high flow water quality data collected in Area I during the Phase I Remedial Investigation (MultiTech, 1987). Acquisition of additional high flow data was necessary to further characterize source areas of metals contaminants and to provide a means of evaluating chemical changes in surface water quality during runoff conditions.

The purpose of sampling for organic compounds during both high and baseflow events in Area I was to: (1) determine if organic compounds are present in the surface water environment of Area I during varying flow regimes; and, (2) determine potential source areas of organic compounds in the Butte area if such compounds were measured.

Results of snowmelt runoff sampling completed during March, 1989 in Area I indicated the following:

- Numerous exceedances of both chronic and acute aquatic water quality criteria and both primary and secondary drinking water standards occurred at several sites sampled during the snowmelt runoff event. The most commonly exceeded aquatic water quality criteria at monitored stations were for total or acid soluble cadmium, lead, copper, and zinc. Primary drinking water standards for arsenic, cadmium, and lead were exceeded at several surface water stations sampled during the snowmelt event.

- Highest concentrations of total and acid soluble metals measured during the snowmelt runoff event generally occurred in water entering the Metro Storm Drain from the Weed Concentrator area and in runoff derived from the Colorado Tailings. Lowest metals concentrations were typically measured in discharge from Blacktail Creek and the Sewage Treatment Plant.

- Arsenic, lead, and iron were generally transported through the surface water system during the snowmelt runoff event in the total fraction. Cadmium in the system was generally in the dissolved form. Copper and zinc were primarily carried in the dissolved fraction in the upper reaches of the Metro Storm Drain and in the total fraction at downstream sampling sites in the lower Metro Storm Drain and Silver Bow Creek.

- The majority of total arsenic, cadmium, lead, copper, and zinc loading in Silver Bow Creek during the snowmelt runoff event was derived from the Metro Storm Drain. The primary iron loading contributor to Silver Bow Creek was Blacktail Creek.

- Organic compounds sampled during the snowmelt runoff event were generally at or below detection limits used in Routine Analytical Services analyses. Detected organic compounds primarily included pesticides; concentrations of identified pesticides were well below any established drinking water standards or health advisories.

Results of organic compound analyses for samples collected during the August, 1989 low flow sampling event were similar to those for the snowmelt runoff sampling event.

Groundwater

The groundwater study completed as part of the Area I Operable Unit Phase II Remedial Investigation consisted of several interrelated components. These included: (1) a surface geophysical survey; (2) installation of monitoring, pumping, and observation wells; (3) groundwater sampling; (4) aquifer testing; and, (5) water level monitoring. The focus of the groundwater investigation was to determine the nature and extent of metals contamination in the area's alluvial groundwater systems. In addition, the groundwater study provided data to better characterize pathways of groundwater movement within the operable unit.

The surface resistivity survey was performed to provide data for use in siting monitoring wells and to gain a general understanding of the depth to bedrock beneath unconsolidated deposits present in Area I. An additional purpose of the resistivity survey was to determine the location and thicknesses of suspected placer deposits along the Silver Bow Creek channel. Identification of such deposits was desirable in evaluating preferential pathways of groundwater movement.

Results of the surface resistivity survey indicated the following:

- Surface resistivity data were useful in identifying areas of shallow groundwater exhibiting high specific conductivity. This information was used to site monitoring wells at locations which would bracket the lateral extent of metals contaminated groundwater.

- Depth to bedrock in the Metro Storm Drain area is generally greater than 200 feet below surface. Depth to bedrock in the vicinity of the manganese stockpile area and the Colorado Tailings is typically less than 40 feet.

- Resistivity data and subsequent drilling activities did not identify any sizable areas of buried placer deposits.

Monitoring wells were installed at 28 locations in Area I during the Phase II Remedial Investigation. ARCO also installed several monitoring wells in the Butte Reduction Works and Colorado Tailings areas during the time the remedial investigation was performed. Paired wells (wells completed at different depths at the same location) were also installed at 14 of the 28 well sites within Area I during the Phase II Remedial Investigation. The purpose of the paired wells was to provide means of characterizing changes in groundwater quality and groundwater elevation with depth in the area's aquifers. Most shallow monitoring well completions in Area I were less than 15 feet below ground surface; deeper monitoring well completions were typically 40 to 60 feet below ground surface.

A relatively deep (268 foot) monitoring well was installed in the vicinity of the City-County shop complex near the upper end of the Metro Storm Drain. The purpose of this well was to determine the vertical extent of metals contamination identified at depth during the Phase I Remedial Investigation (MultiTech, 1987). Material samples collected at this site during borehole advancement were also analyzed to determine if metals contamination in deeper zones in the groundwater system were attributable to natural mineralization of sediments.

Information and data collected during drilling activities associated with monitoring well installation in Area I indicated the following:

- Site lithologies generally consist of fill material, waste rock, slag, and mine and mill tailings underlain by alternating sequences of sand, sand and gravel, silt, and clayey silt units. Correlation of individual lithologic units laterally is difficult.

- Observations made during drilling activities in Area I indicate that the relatively coarse sand and sand and gravel units generally yielded 15 to 20 gallons per minute (gpm). Finer grained units yielded less than 5 gpm during drilling.

- A relatively well sorted gravel unit was encountered at a depth of 210 feet below ground surface in the upper Metro Storm Drain area near the City-County shop complex. This 20 foot thick unit yielded greater than 100 gpm during borehole advancement.

- The uppermost water-bearing unit was generally encountered within 10 feet of the surface except in the upper Metro Storm Drain area where depth to water is 20 to 30 feet below surface. Where tailings were identified in the boreholes, groundwater was generally encountered within one to two feet below the base of the tailings.

Groundwater sampling events were completed during the Phase II Remedial Investigation during August and November, 1989. Sampled wells included monitoring wells installed during both the Phase I and Phase II Remedial Investigations, selected monitoring wells installed previously by ARCO and the Montana Bureau of Mines and Geology, and selected domestic wells. Sampled wells provided data with which to characterize metals contaminants both spatially and vertically throughout the study area. Collected samples were analyzed for dissolved metals, common ions, and nutrients.

Results of groundwater sampling completed during the Phase II Remedial Investigation indicated the following:

- There are three general source areas of metals-contaminated groundwater in Area I. These include the City-County shop complex area, the Butte Reduction Works tailings impoundments-Butte Sewage Treatment Plant area, and the Colorado Tailings. The primary metal contaminants in these areas are copper, zinc, cadmium, lead, arsenic, iron, and manganese. Concentrations of metals in these areas are two to four orders of magnitude higher than in areas located upgradient and cross-gradient.

- Metal concentrations generally decrease with increasing distance from the three general source areas.

- One or more exceedances of primary drinking water standards for arsenic, cadmium, lead, nitrate + nitrite as nitrogen, and fluoride were measured in groundwater samples collected from 37 monitoring wells and two domestic wells. The total area of the alluvial groundwater system within Area I which exceeds primary drinking water standards is about 400 acres.

- Metals concentrations typically decrease with depth in the area's groundwater systems. The depth to which groundwater exceeds primary drinking water standards in the upper Metro Storm Drain area is approximately 150 feet below ground surface; this depth decreases to about 50 to 60 feet below ground surface in the vicinity of Kaw Avenue near the lower end of the Metro Storm Drain.

X-ray diffraction data for material samples collected at depth in the upper Metro Storm Drain area indicate metals-contaminated groundwater is not the result of natural mineralization of the host sediments.

Metals concentrations also decrease with depth rapidly in the vicinity of the Butte Reduction Works tailings impoundments and the Butte Sewage Treatment Plant. However, metals concentrations appear to increase with depth into the underlying bedrock groundwater system in the vicinity of the Colorado Tailings; a lower bound to metals contamination in groundwater beneath the Colorado Tailings was not determined during this study.

- A calcium-bicarbonate type water is generally associated with groundwater which is not impacted by metals contaminants. Groundwater which contains relatively high concentrations of metals is generally a calcium-sulfate type water.

Aquifer testing completed during the Area I Operable Unit Phase II Remedial Investigation consisted of two components. Slug testing was completed in 46 monitoring wells throughout the study area to gain a general understanding of the relative differences in permeability at various depths in the groundwater system. In addition, long-term pumping tests were performed at four locations within the study area to provide more definitive data regarding hydraulic characteristics of the shallow groundwater system.

Results of these aquifer tests indicated the following:

- The shallow groundwater system in the upper Metro Storm Drain area near the City-County shop complex exhibits low hydraulic conductivity, on the order of 2.5 ft/day. Phase I Remedial Investigation aquifer test data (MultiTech, 1987) suggest that this relatively low hydraulic conductivity environment extends to about 200 feet below ground surface in this area.

- The shallow groundwater system in the middle and lower reaches of the Metro Storm Drain area exhibits relatively higher hydraulic conductivities than the upper Metro Storm Drain area. Calculated hydraulic conductivities in this portion of the study area are on the order of 15 ft./day.

- The shallow groundwater system in the vicinity of the historic Butte Reduction Works tailings impoundments displayed the highest hydraulic conductivities measured in Area I. Calculated hydraulic conductivities in this area were about 150 ft./day.

- Calculated hydraulic conductivities for the shallow groundwater system underlying the Colorado Tailings were relatively low, on the order of 15 to 20 ft./day.

Water level data collected during the Phase II Remedial Investigation were used to evaluate groundwater flow directions and horizontal and vertical groundwater gradients. These data indicate the following:

- The shallow alluvial groundwater system in the vicinity of the Weed Concentrator and City-County shop complex is relatively flat. A groundwater divide is present in the alluvial groundwater system in the vicinity of Continental Drive. Groundwater north of this divide moves toward the Berkeley Pit; groundwater south of this divide moves to the southwest, parallel to the Metro Storm Drain.

- Recharge to the alluvial groundwater system in Area I is derived from the east, south of the Berkeley Pit, from the Blacktail Creek alluvial system, and from groundwater systems entering from Butte Hill and the foothills south of the Colorado Tailings.

- Lateral groundwater gradients in the alluvium in Area I range from about 0.3% in the middle reaches of the Metro Storm Drain area to about 0.1% in the vicinity of the Butte Reduction Works area.

- Groundwater movement is generally parallel to and toward the Metro Storm Drain and Silver Bow Creek. Data indicate both the Metro Storm Drain and Silver Bow Creek are gaining water from groundwater inflow throughout the study area with the exception of the reach of the Metro Storm Drain above Harrison Avenue.

- Vertical groundwater movement is downward in the upper Metro Storm Drain area and in the area south of the Colorado Tailings at gradients ranging from 2 to 9%. Groundwater discharge areas were identified in the lower Metro Storm Drain area and near the west end of the Colorado Tailings. Upward vertical gradients in these areas ranged from 1.5 to 8%. There was no significant trend to vertical groundwater gradients in the portion of the study area between Montana Street and the Butte Sewage Treatment Plant.

Soils

Soils investigations completed during the Area I Operable Unit Phase II Remedial Investigation focused on identifying and sampling the various types of materials present within the study area. No efforts were made to directly characterize soils in residential areas within or adjacent to the Area I study area; this type of study is being completed by the USEPA throughout Butte. Soils data collected during the Phase II Remedial Investigation in Area I, however, will be directly applicable to USEPA studies in Butte.

Three general activities were conducted as part of the soils study in Area I. These consisted of a soils mapping effort, sampling of dispersed tailings and contaminated soils, and sampling and characterization of impounded tailing deposits. The soils mapping task was completed to identify and describe the various material types present within the study area. The mapping effort provided a basis from which soils/tailings sampling sites were selected.

The dispersed tailings/contaminated soils and impounded tailings sampling efforts were completed to provide chemical and physical data for the various map units identified during the soils mapping effort. In addition, approximate volumes of contaminated material were calculated using these data. Data generated during the soils investigations will be used to evaluate risk to public health and the environment and will also be used to support evaluations of cleanup alternatives.

Data acquired during the soils and tailings investigations completed during the Area I Operable Unit Phase II Remedial Investigation indicate the following:

- Site soils consist of a variety of material types which can be differentiated primarily on the basis of texture, color, and location.

- Material types present in Area I include both natural soils and sediments and man-emplaced materials. Natural soils and sediments include upland soils and colluvial sediments, alluvial sands and gravels, and floodplain peat and clay deposits. Man-emplaced materials include landfill materials, waste rock fill, mine and mill tailings placed in impounded facilities, low grade ore and sulfidic materials used for railroad fill, and flood deposited mixtures of tailings and alluvium.

- Subsurface materials are generally intermixed; the lateral variability in material types could not be accurately mapped in the subsurface with the level of subsurface information gathered during this investigation.

- Three material types are the primary sources of metals in Area I. These include exposed tailings (material unit 1), covered tailings (material unit 2), and mixed tailings and alluvium (material unit 4). These material units were found in greatest abundance in the vicinity of the historic Parrott Smelter at the upper end of the Metro Storm Drain, in the vicinity of the historic Butte Reduction Works tailing impoundments, and in the Colorado Tailings area.

- Other materials which exhibited relatively high metals concentrations included railroad ballast beneath an abandoned line in the vicinity of the manganese stockpile area and tailing deposits located beneath slag walls in the manganese stockpile area.

- Finer grained material associated with surface (0 to 1 inch) samples collected from exposed areas within the operable unit exhibited relatively higher metals concentrations than coarser fractions.

- Metals, particularly copper and zinc, in exposed tailings material solubilize in water.

- Sampling for organic compounds completed in Area I proximal to the Montana Pole Superfund site produced data which indicated petroleum hydrocarbon contamination (primarily toluenes) was present in a subsurface sample obtained near the product recovery trench at the site. The data indicated that the extent of petroleum hydrocarbons in the soils in this portion of Area I is limited and that the source of the compounds is the Montana Pole site. Samples for organic compound analysis were not collected elsewhere in Area I during this investigation.

- Several samples collected for EP Toxicity analyses exceeded maximum concentrations of contaminants defined by the USEPA for lead and cadmium.

Conceptual Description of Site Conditions

Data gathered during the Phase II Remedial Investigation and other data available for the Butte area provide a reasonable basis from which problems in Area I can be identified and from which general concepts can be developed regarding contaminant sources, pathways, and receptors in the operable unit. Contaminants in Area I are primarily associated with various metals parameters including copper, zinc, lead, arsenic, cadmium, and iron. Available data suggest there is little evidence of organic contamination in Area I with the exception of hydrocarbon-related compounds adjacent to the Montana Pole Superfund site. It is probable that the presence of these compounds in this portion of the study area is associated with source areas already identified at the Montana Pole site.

Contaminant Source Areas

The primary source areas of metals contaminants in Area I include the historic Parrott Smelter tailings and waste deposits, the historic Butte Reduction Works tailing impoundments and associated slag deposits, and the Colorado Tailings. The majority of source material (tailings) associated with the historic Parrott Smelter has been covered with fill material to facilitate commercial and residential construction. Because of this, the source material in this portion of the study area is present at depths ranging from 10 to 30 feet below surface and ranges in thickness from a few inches to over seven feet. The approximate volume of metals-enriched material in the vicinity of the Parrott Tailings is 650,000 cubic yards. For purposes of this report, "metals-enriched" is defined as that material which exhibits metals concentrations one to two orders of magnitude higher than adjacent or subjacent material.

Sources of metals-enriched material in the Butte Reduction Works and Colorado Tailings areas are at and near the surface. Thicknesses of metals-enriched material in the Butte Reduction Works and Colorado Tailings are about 10-15 feet and 6-8 feet, respectively. The estimated volume of metals-enriched material associated with the Butte Reduction Works-Sewage Treatment Plant area within Area I is 1.6 million cubic yards of which approximately 430,000 cubic yards are either tailings or mixed alluvium-tailings material and 130,000 cubic yards are associated with railroad ballast. This volume estimate does not include slag walls or stockpiles of manganese present in the area. The volume of metals-enriched material in the Colorado Tailings area is about 600,000 cubic yards of which approximately 230,000 cubic yards are tailings material.

Numerous other metals-enriched areas are present within Area I between the major source areas. Several factors appear to affect the tendency for metals to migrate from a particular metals-enriched sediment deposit in Area I to a receptor or another environmental media. These include factors such as whether the metals-enriched deposit is exposed or buried, whether groundwater intercepts the deposit, the location of the deposit with respect to surface water courses, and the intensity of vegetation overlying the deposit. Most metals-enriched areas outside of the three primary source areas in Area I are in locations which appear to minimize the potential of metals migration with respect to the foregoing factors.

Contaminant Pathways

Metals contaminants in Area I are transported in the environment by three primary mechanisms. These include air, surface runoff, and groundwater. The air pathway was not directly evaluated during the Phase II Remedial Investigation; this pathway was evaluated indirectly through analysis of metals by various grain sizes in material which is subject to airborne transport. These data indicated that finer grained fractions (< 200 mesh) of sampled surface (0 to 1 inch) soil samples generally contained higher metals concentrations than coarser grained fractions. Actual concentrations of metals in the fine-grained fractions were variable between soil map units.

Surface runoff was evaluated during both the Phase I and Phase II Remedial Investigations. These data indicate that the majority of metals transported during in-bank runoff events are derived from source areas outside of Area I, primarily on Butte Hill. A component of metals in surface water during surface runoff events, however, is derived from within Area I. Surface soils data collected during the Phase II Remedial Investigation suggest that certain locations within Area I contain metals in surface soils and tailings which readily solubilize in water.

Groundwater is an important pathway for transporting metals to surface water in Area I and is probably the primary contributor of metals to Silver Bow Creek during low flow and baseflow conditions. A downward vertical gradient in the groundwater system appears to move metals-contaminated groundwater from upper portions of the groundwater system to as deep as approximately 150 feet below ground surface in the vicinity of the Parrott

Tailings. X-ray diffraction analyses of material samples collected at these depths indicate that the material hosting this metals-laden groundwater is not naturally mineralized and is therefore not a source for elevated metals concentrations in groundwater occurring at these depths. Downward groundwater gradients in this area may be caused by a 20-foot thick higher permeability sand and gravel unit identified at a depth of approximately 210 feet below ground surface or it may be related to a dewatered portion of the underlying bedrock system caused by historical pumping from the Berkeley Pit area.

Groundwater in the vicinity of the Parrott Tailings also moves laterally, parallel to the Metro Storm Drain. In the vicinity of Harrison Avenue, the base of the Metro Storm Drain intercepts the shallow groundwater system causing surface flow in the normally dry channel. An upward groundwater gradient measured in the lower Metro Storm Drain area also serves to provide additional flow to the Metro Storm Drain.

Groundwater movement in the vicinity of the Butte Reduction Works and Sewage Treatment Plant area is generally horizontal. Contaminated groundwater in this vicinity moves laterally into Silver Bow Creek.

Shallow groundwater in the Colorado Tailings area appears to move from the southeast to the northwest and eventually enters Silver Bow Creek. A relatively strong downward component to groundwater movement is evident near the southern edge of the Colorado Tailings and to the east of the deposit. This may cause a component of the groundwater system to move shallow contaminants to depth and into the underlying bedrock system. An upward groundwater gradient occurs at the west edge of the Colorado Tailings and to the west of the deposit. This situation is likely caused by a bedrock constriction located in this area which decreases the thickness of the alluvial aquifer. This phenomenon probably moves metal contaminants at depth upward and into Silver Bow Creek.

Site Problems

General problems identified in Area I during the remedial investigation include the following:

- Large areas of surface contamination, comprised of tailings and contaminated soils, are present within the boundaries of the operable unit. These materials contain elevated levels of several metals and, in some cases, are sparsely vegetated or barren of vegetation. The most prominent exposed area within Area I is the Colorado Tailings. Exposed tailings and contaminated soils are available for human and animal exposure. These exposed areas are also susceptible to erosion and entrainment during snowmelt and precipitation-induced runoff events. Because large expanses of exposed tailings and contaminated soils are located within the floodplain of Silver Bow Creek, the material is also subject to entrainment during major flood events. The eventual impact of runoff from these areas due to snowmelt, precipitation, or floods is

realized in degraded water quality and aggradation in receiving surface water courses.

- Exceedances of both chronic and acute aquatic water quality standards are common in both the Metro Storm Drain and Silver Bow Creek. During higher flow events caused by snowmelt or precipitation runoff input to surface water courses, exceedances of primary and secondary drinking water standards in Silver Bow Creek are also commonplace.

  Sources of chronic metals contamination in the Metro Storm Drain and Silver Bow Creek are derived primarily from inflow of contaminated groundwater. Acute metals contamination in the Metro Storm Drain and Silver Bow Creek is realized from surface runoff. The primary sources of metals contamination to surface runoff are located largely outside of Area I on Butte Hill.

- Metals are transported out of Area I in several forms, primarily by Silver Bow Creek, and, to a lesser extent, by groundwater. These transported metals deleteriously affect downstream water quality.

- A large volume of subsurface material also containing elevated metals concentrations is present within the operable unit. Metals concentrations in this material is one to two orders of magnitude higher than concentrations measured in adjacent and subjacent materials. These materials represent sources of metals contamination to groundwater through precipitation infiltration and through contact with groundwater caused by fluctuations in groundwater elevation. The most prominent source areas which impact groundwater resources in Area I include the historic Parrott Smelter and associated tailing and slag waste deposits, the historic Butte Reduction Works tailing impoundments and associated slag deposits beneath the Butte Sewage Treatment Plant, and the Colorado Tailings.

  Metals-contaminated groundwater moves dynamically within Area I but eventually discharges into surface water courses including the Metro Storm Drain and Silver Bow Creek. Groundwater impacts on receiving surface water courses becomes most prominent during low flow and baseflow conditions in the Metro Storm Drain and Silver Bow Creek.

- A large portion of the alluvial groundwater system in Area I contains water which exceeds both primary and secondary drinking water standards. This resource is currently unusable as a potable water supply.

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SECTION 1.0 INTRODUCTION

1.0 INTRODUCTION

This data summary report presents and summarizes environmental data collected during the Phase II Remedial Investigation (RI) at the Area I Operable Unit. The Area I Operable Unit is a portion of the larger Silver Bow Creek Superfund site, which was placed on the Superfund National Priorities List in September, 1983. Area I is the second operable unit to undergo a Phase II RI in the Silver Bow Creek Superfund site. The Warm Springs Ponds Phase II RI and Feasibility Study (FS) were completed during 1989 (CH2M HILL, 1989a and 1989b).

MultiTech (1987) reports results of Phase I RI activities at the Silver Bow Creek CERCLA site. A portion of the investigative activities performed during that study were completed within the Area I Operable Unit. Following completion of the Phase I RI, several gaps were identified in the data needed to fully characterize contaminant sources and pathways of contaminant movement in the Area I Operable Unit (CH2M HILL, 1989c).

Investigations conducted at the Area I Operable Unit during the Phase II RI included sampling and analysis of surface water, groundwater, and contaminated soils and tailings. The primary contaminants of concern within the operable unit are heavy metals, including copper, zinc, cadmium, arsenic, lead, and iron.

This data summary report is arranged by environmental media investigated during the Phase II RI. A brief description of field activities and data collection methods used during the various investigations is presented first within each section of the report, followed by a summary of results. These sections are followed by an evaluation of the quality of data generated during the study and a summary of contaminant sources, pathways, and receptors in Area I.

Exhaustive interpretations of collected data are not included in this document. More complete analyses will be completed, as necessary, during future studies of the operable unit. Various data bases created during this study and other pertinent information are presented in appendices which accompany this report (Volume II).

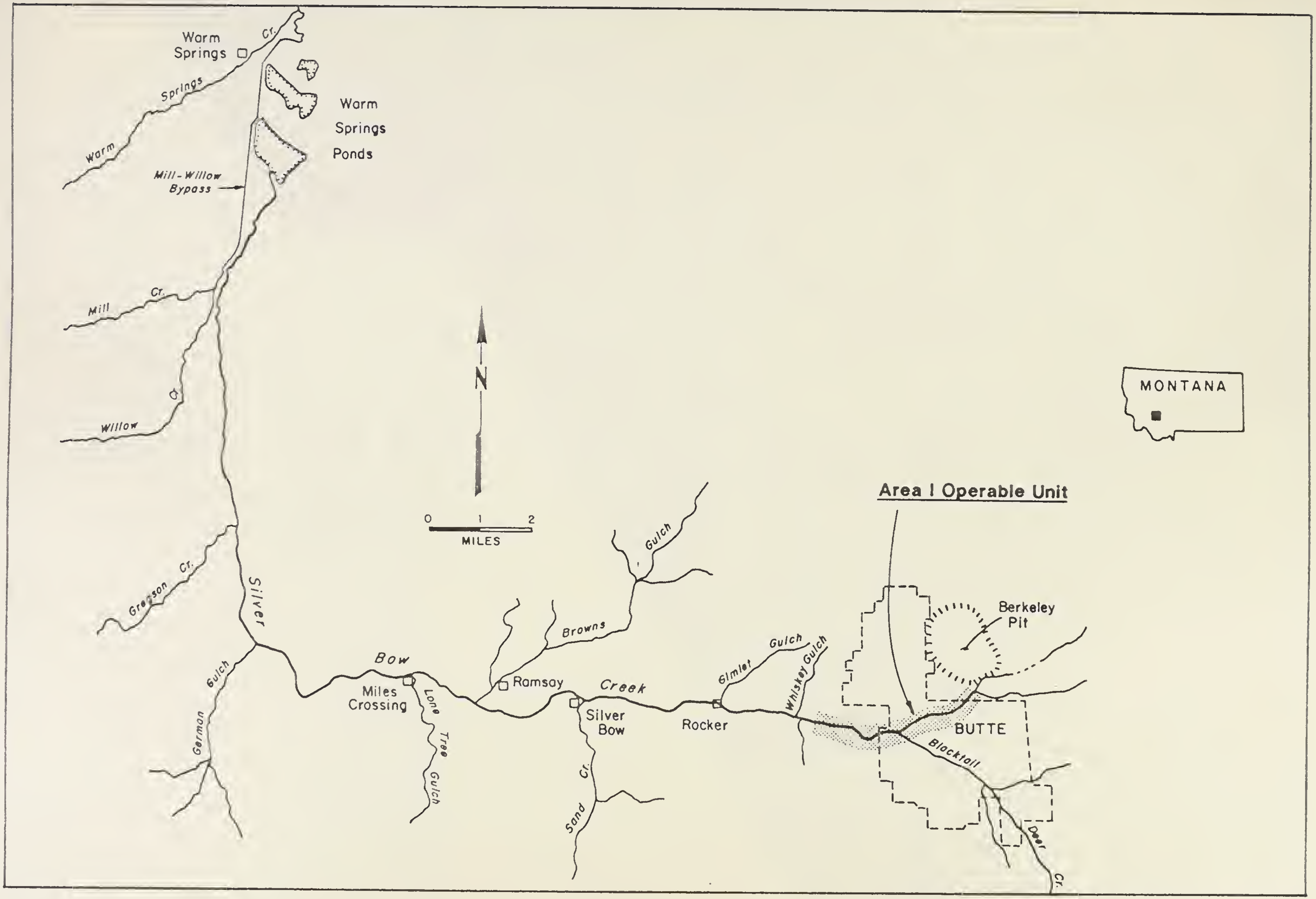
Methods used to collect environmental samples during the Area I Operable Unit Phase II RI are described in the project work plan and the project sampling and analysis plan (CH2M HILL, 1989c, 1989d). Changes to these plans and the consequences of those changes are described herein.

1.1 PROJECT BACKGROUND

Area I is a designation that describes a specific portion of the Silver Bow Creek CERCLA site. Area I is located primarily within and adjacent to urbanized areas of the city of Butte, Montana (Figure 1-1). The Area I Operable Unit study area generally parallels the Butte-Metro Storm Drain from below the Weed Concentrator to its mouth and the reach of Silver Bow Creek from below the confluence of Blacktail Creek and the Metro Storm Drain to below the Colorado Tailings (Figure 1-2).

Silver Bow Creek and contiguous portions of the upper Clark Fork River were listed as a Superfund site in September, 1983 by the U.S. Environmental Protection Agency (EPA) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The site currently extends from Butte to Milltown, Montana, some 140 river miles. The Solid and Hazardous Waste Bureau of the Montana Department of Health and Environmental Sciences (MDHES) formerly administered EPA appropriations and directed efforts to conduct remedial investigations associated with the site. Currently, EPA is administering all Superfund activities in the Butte area. Area I was designated as an operable unit because the contaminant sources and pathways of contaminant movement within the area are consistent and are somewhat unique with respect to adjacent areas.

The Montana Pole and Treating Company Superfund site is adjacent to the Area I Operable Unit. The Area I Operable Unit is also surrounded on three sides by the Butte Addition to the Silver Bow Creek Superfund site which includes Butte Hill, the Berkeley Pit, the Clark-Timber Butte Tailings, and areas hosting mine flooding in the west camp of Butte near the Travona mine shaft. Efforts were made during the Area I Phase II RI to coordinate field activities among the various studies to maximize data usage between sites, prevent overlap of study efforts, and minimize redundancy in gathered data.



Silver Bow Creek CERCLA Site Index Map

FIGURE 1-1

BUTTE HILL
STREET
MONTANA
STREET
MISSOULA
BUTTE
REDUCTION
WORKS
TAILINGS
RANCHLAND
PACKING COMPANY
STREET

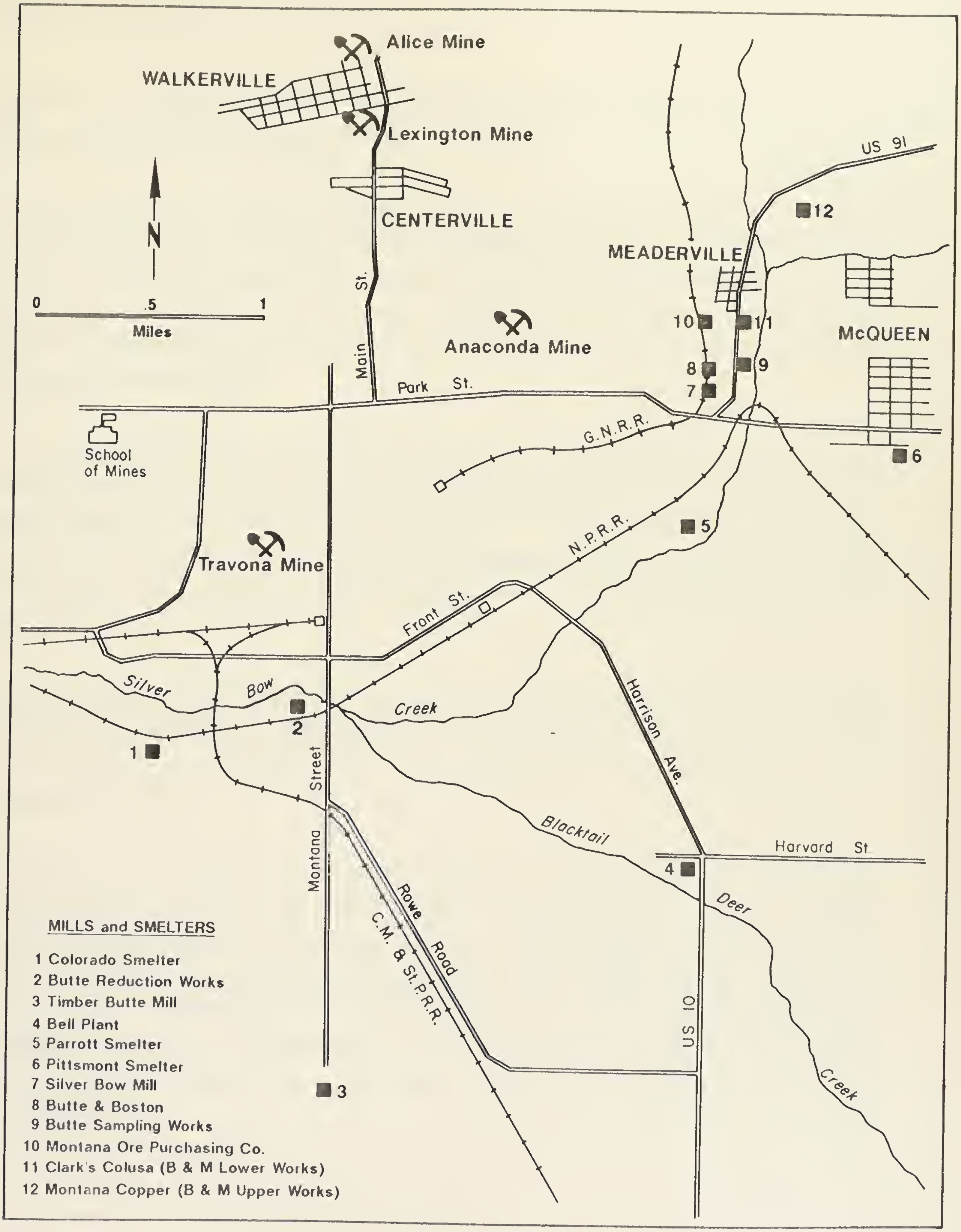
The Phase I Remedial Investigation completed for the Silver Bow Creek CERCLA site (MultiTech, 1987) preliminarily characterized environmental conditions in the Area I Operable Unit. A summary of data derived from the Phase I investigation and other historic data for the Area I Operable Unit are presented in the Area I Phase II RI work plan (CH2M HILL, 1989c). The work plan also describes known and suspected contaminant sources, probable transport pathways, specific data gaps, and methods to fill identified data gaps.

1.2 GENERAL SITE HISTORY

The history of man's activities along Silver Bow Creek within and adjacent to the Area I Operable Unit is long and varied. The first record of any disturbance of the stream's natural channel is in 1864 when placer mining commenced along Silver Bow Creek (Freeman, 1900; Meinzer, 1914; Smith, 1952). Placer mining techniques were used to extract low-grade gold deposits along Silver Bow Creek and its tributaries, particularly along Missoula Gulch (Figure 1-2). The majority of placer operations in the area had ceased by 1869, although a small contingent of placer miners continued placering local streams after this date.

Concurrent with placer mining along Silver Bow Creek, hard rock mining started on mineralized veins outcropping on Butte Hill, north of Silver Bow Creek. Several small smelters/concentrators and a wet-process quartz mill (Davis Mill) were built from 1866 to 1868 along Silver Bow Creek to process ore (Smith, 1952). Although some copper and silver were produced, all facilities were closed by 1869. Apparently, little mining activity occurred in the Butte area from 1869-1874.

William Farlin restaked some mining claims on the Butte Hill in 1875 as a result of favorable silver ore assays found in the area (Smith, 1952). This rejuvenated mining activity in Butte and by 1878 several small smelters were operating in the area. By 1881, Butte had become one of the nation's major mining centers; the district attained national dominance in copper mining by the mid-1890s and international prominence by the turn of the century. Between 1879 and 1885, at least six major smelters were built along Silver Bow Creek from Meaderville to Williamsburg (HRA, 1983; Smith, 1952; Meinzer, 1914; Freeman, 1900). Locations of these smelters are shown on Figure 1-3. A smelter was also constructed at the



from: Smith (1952)
rev: USGS (1903)

Early Reduction Plants in Butte
FIGURE 1-3

new town of Anaconda in 1884 by Marcus Daly, one of the founders of the Anaconda Copper Mining Company (Smith, 1952).

The major smelters constructed along Silver Bow Creek operated nearly continuously until 1910 (HRA, 1983). By 1910, Anaconda Copper Mining Company had purchased and closed all but one of the major concentrators/smelters (the Pittsmont) located adjacent to Silver Bow Creek; most of the ore was shipped to the smelter in Anaconda for processing. This practice continued until 1980 when the smelter in Anaconda was closed. The Pittsmont Smelter operated until 1930.

The Timber Butte Mill, located south of Silver Bow Creek (Figure 1-3) operated until approximately 1930. Tailings from the Timber Butte Mill, Butte and Superior, and East Butte concentrators were sluiced in various amounts to tributaries of Silver Bow Creek until at least 1918 (MultiTech, 1987). Milling and smelting operations adjacent to Silver Bow Creek generated an estimated total of 10 million tons of waste from 1878-1925 (MultiTech, 1987).

Large-scale underground mining continued in Butte during the early- to mid-1900's. In 1955, Anaconda Copper Mining Company commenced open-pit mining at the Berkeley Pit. Low-grade copper ore mined from this source was processed at the Weed Concentrator in Butte, constructed in 1963.

Silver Bow Creek continued to receive raw mining and milling wastes until 1972, when a treatment plant was added to the Weed Concentrator (Spindler, 1976). In 1977, Anaconda Copper Mining Company was merged with the Atlantic Richfield Company (ARCO). ARCO closed all underground mining operations in Butte in 1980 because of a depressed copper market. ARCO likewise closed the Berkeley Pit in 1982 and the adjacent East Berkeley Pit in 1983. The underground mines beneath Butte and the Berkeley Pit were allowed to flood and water levels in the area are currently rising in response to the cessation of pumping.

In 1986, Montana Resources Inc. (MRI) purchased Anaconda's Butte Operations (including the Berkeley Pit, East Berkeley Pit, Continental East Pit, and the Yankee Doodle Tailings Ponds). In 1989, American Smelting and Refining Company (ASARCO) purchased minority ownership of MRI's Butte operations. MRI and ASARCO are currently mining copper-ore from the East Berkeley Pit and are processing mined ore at the Weed Concentrator. There are currently no direct surface discharges from MRI's operation to Silver Bow Creek.

1.3 HISTORY OF SITE CONTAMINATION

Area I and adjacent areas have historically been a center of mining, milling, and smelting activity, primarily involving the Parrott Smelter and other mills and smelters in the upper portion of the study area near the Metro Storm Drain, and the Butte Reduction Works Mill and the Colorado Smelter in the lower portions of the study area (Figure 1-2). The upper portion of the study area lies within residential and commercial areas of the city of Butte. The Metro Storm Drain was constructed through the area during the 1930's to provide a means of transporting storm runoff out of Butte. The Metro Storm Drain generally follows the historic course of Silver Bow Creek. Wastes from several mills and from mining activities in the general vicinity of the present day Weed Concentrator were deposited directly into historic Silver Bow Creek or were contained in tailings ponds constructed adjacent to the stream.

It is probable that a portion of wastes released to surface water courses in the Butte area was transported out of Butte by Silver Bow Creek. However, a sizable volume of wastes remained within and adjacent to the historic stream channel and within constructed tailing ponds. Wastes remaining in the area have largely been covered or filled over and thus are not readily visible at the surface today. Construction of the Berkeley Pit and associated facilities also resulted in removal of much of the deposited wastes in areas above the present day Weed Concentrator complex.

The Parrott Smelter (Figures 1-2 and 1-3) was one of the largest facilities that historically impacted areas along the upper reaches of Area I. It was opened in 1881 and terminated operations in 1910, following the Anaconda Company's acquisition of the mill (Smith, 1952). Peak annual copper production at the mill was over 14 million pounds (HRA, 1983). Limited drilling completed during the Phase I RI (MultiTech, 1987) confirmed the presence

of buried tailings material in the general vicinity of the historic Parrott Smelter tailings pond.

The lower portion of Area I (from Montana Street to below the Colorado Tailings) is located in an area that has historically hosted milling and smelting activity, associated primarily with four mills: the Butte Reduction Works Mill, the Domestic Manganese and Development Company facility, the Rocky Mountain Phosphates operation, and the Colorado Smelter (Figure 1-2). The Butte Reduction Works were constructed in 1883 and operated nearly continuously until 1911 when a fire destroyed the plant (HRA, 1983). Peak annual copper production of the smelter was over 19 million pounds.

The Domestic Manganese and Development Company facility began operations in 1928 and was closed in about 1959 (HRA, 1983). The plant beneficiated manganese ore. The Rocky Mountain Phosphates operation commenced operation at the same site in 1960. This plant produced tricalcium phosphate animal feed supplement until its closure in 1964 (HRA, 1983).

The Colorado Smelter was constructed in 1878 and operated until about 1904. This smelter reached peak production in 1902 with an annual copper production of over 10 million pounds (HRA, 1983). Tailings resulting from the operation of the facility were deposited on to the Silver Bow Creek floodplain. Through time, the area of tailings disposal encroached on Silver Bow Creek necessitating rechannelization of the stream to the north.

The lower portion of Area I is currently characterized by mining, smelting, and milling waste deposits. It is bordered to the north by light industrial facilities, to the south by Interstate 90/15, and to the east by the city of Butte. Silver Bow Creek exits the valley to the west. The Butte sewage treatment plant is also located in this area as are stockpiles of manganese. Several manganese slag walls are present in the area confining tailings and channelizing Silver Bow Creek as it flows through the area. Missoula Gulch is the largest tributary entering Silver Bow Creek in this area. Missoula Gulch is an intermittent drainage with little discharge, except during spring snowmelt or during precipitation events. The Colorado Tailings are a sizable geomorphic feature in the lower end of Area I. This tailings deposit is generally barren of vegetation and covers an area of approximately 40 acres.

Other features of interest adjacent to the lower reaches of Area I include the Montana Pole and Treating Company facility located south of the Butte Reduction Works area, and Montana Power Company's transformer storage yard. The Montana Pole site contains documented organic contamination associated with historic use of pentachlorophenol (PCP) and diesel at the facility; the site is currently undergoing remediation under the auspices of the EPA and is also scheduled for a RI/FS in the near future. The transformer storage yard may be a source of organic contamination.

1.4 SITE DESCRIPTION

Approximate boundaries of the Area I Operable Unit are depicted in Figure 1-2. The lateral extent of the study area in the vicinity of the Metro Storm Drain incorporates surface areas that drain directly to the Metro Storm Drain. Areas draining to storm sewers that enter the Metro Storm Drain and Missoula Gulch and eventually into Silver Bow Creek were excluded from the Area I study area. These potential sources of contamination were evaluated during this study as point source inputs (storm sewer outfalls) to Area I. Likewise, no efforts were made during this study to directly characterize contaminant sources and pathways in the Weed Concentrator area. Areas not evaluated during the Area I Phase II Remedial Investigation are being studied in conjunction with other studies being completed on Butte Hill by the EPA.

Residential areas within Area I were generally excluded from the study area. Some isolated residences present within the study area boundary (Figure 1-2) were evaluated with respect to environmental impacts on surface water systems; no specific efforts were made to characterize these residences from a human health perspective. Studies directed toward evaluating human health risks associated with residential areas in Butte is being completed in a separate EPA study of the Butte Hill.

The study area for groundwater investigations in Area I was more widespread than that for other environmental media, particularly in the vicinity of the Metro Storm Drain (Figure 1-2). The study area boundary for groundwater investigations was expanded in the vicinity of the Metro Storm Drain in an attempt to determine the spatial extent of inorganic contaminants in groundwater derived from sources located within the general study area. The upper (northeastern) boundary of the groundwater study area along the Metro Storm

Drain was generally coincident with location of a groundwater divide caused by the Berkeley Pit. For purposes of this study, it was assumed that the water level in the Berkeley Pit will be maintained at a sufficient depth such that the presence of the groundwater divide in the upper Metro Storm Drain area is maintained. The bedrock groundwater system in the vicinity of Area I is not included in this study but is being evaluated under EPA's studies of the Butte Hill.

1.5 SITE CHARACTERISTICS

1.5.1 <u>Physiography/Demography</u>

The Area I Operable Unit is located just west of the Continental Divide in southwestern Montana at an elevation of approximately 5400 feet above mean sea level. The site is included in the Northern Rocky Mountain physiographic province. Area I is located on the northern flanks of the Summit Valley which is characterized by gently sloping terrain bound by mountains associated with the Boulder Batholith and Continental Divide to the north and east. The area to the south is typified by the Summit Valley which hosts Blacktail Creek. Blacktail Creek originates in the Highland Mountains located approximately 15 air miles south of Butte. To the west, moderately steep hills are present which intrude on the valley bottom.

The Area I Operable Unit covers an area of approximately 500 acres. The upper (northeastern) portion of the study area is typified by residential and commercial development; the Weed Concentrator associated with Montana Resource, Inc.'s mining operations is present at the upper end of the area. The lower (southwestern) portion of the study area is characterized by light industrial activity and scattered residences. Manganese stockpiles, slag walls, and tailing deposits are also present in the lower end of the study area.

The study area is located within and adjacent to the city of Butte. Butte has historically been a center for mining activities for the region, particularly in conjunction with copper mining. The estimated population for Butte-Silver Bow in 1988 was 33,200 (U.S. Bureau of Census, 1989). In 1980, the city-county had a population of 38,092 (U.S. Bureau of

Census, 1980); population in Butte-Silver Bow peaked in 1920 at a 60,313 persons (Dodge, 1976).

Portions of the city of Butte are directly adjacent to the Area I Operable Unit. Approximately 50 individual households are located within the defined study area boundary used for soils investigations. The Butte-Silver Bow shop complex is present within the operable unit at the upper end of the study area. The Butte Civic Center is also located within the middle portion of the operable unit. Other major demographic features within the study area include a retirement home, a commercial campground, a restaurant, an asphalt recycling center, Butte's sewage treatment plant, and a meat packing plant.

1.5.2 Climate

The Butte area has a continental climate characterized by moderately warm days in summer and cold winters. Average mid-summer temperatures average between 60° and 65° F; average mid-winter temperatures are about 20° F. Temperature extremes rarely exceed 100° F and often are well below zero. Record recorded extreme temperatures in Butte are 100° F on July 21, 1931 and minus 52° F on February 9, 1933 and December 23, 1983.

Annual precipitation in Butte varies from six to 20 inches; the average annual precipitation is 11.72 inches for the period of record from 1951 to 1988 (NOAA, 1988). The greatest amount of precipitation typically occurs during the months of May and June. Precipitation during the winter months typically occurs as snow. Measurable snowcover in the Butte area has occurred during all months of the year. The average growing season in Butte is 81 days (NOAA, 1971). The average first frost occurs on August 28; the average last killing frost occurs on June 8 (NOAA, 1971).

1.5.3 Geology

The geology of the Area I Operable Unit is diverse with rocks ranging from Cretaceous intrusives to Quaternary alluvium. Rocks in the Butte area are largely siliceous with zones containing ore-grade sulfide minerals and other associated sulfide deposits. The Boulder Batholith bounds Area I to the north; this feature is composed primarily of highly mineralized quartz monzonite.

Tertiary-aged unconsolidated valley fill and alluvial deposits associated with Silver Bow Creek are present throughout Area I ranging in thickness from over 300 feet near the upper end of Area I to less than 30 feet in the vicinity of the Colorado Tailings. These deposits consist of poorly sorted gravel, sand, silt, and clay which are not easily correlatable laterally (MultiTech, 1987). Isolated cobbles and boulders are also present within these sediments.

The Butte Mining District has been a major producer of gold, silver, and copper, with lesser quantities of cadmium, bismuth, arsenic, selenium, and tellurium (Miller, 1973). Tailings, waste rock, leach pond deposits, and smelter wastes are present at numerous sites in the Butte area. These deposits generally overlie alluvium, colluvium, or fractured bedrock and are occasionally covered over by man-emplaced fill material.

1.5.4 Soils

A diversity of soil types is present in the Area I Operable Unit study area. Soils within the study area were developed primarily on upland slopes under conifer forests or on valley-fill sediments under grassland vegetation. Adjacent to Silver Bow Creek, thin gravel-textured to deep, fine-grained alluvial soils have developed. Nutrient rich, organic soils (peat) of various thicknesses are present in some low or wetland areas.

Surfaces on which natural soils developed have been altered by man through much of Area I. The original land surface along the historic course of Silver Bow Creek has been buried by mining waste or other man-emplaced fill materials or have been disturbed through urban development activities. Man-emplaced deposits vary substantially in metal levels.

Mining-related wastes in the study area are generally sandy textured because of milling activities, and typically contain high concentrations of metals and sulfide minerals. Generally, oxidation of sulfide minerals produces acidic conditions that increase the solubility of heavy metals. These processes limit vegetation establishment which further limits soil development.

1.5.5 Surface Hydrology

The surface water system in the Area I Operable Unit consists of three primary components: the Metro Storm Drain, Blacktail Creek, and Silver Bow Creek (Figure 1-1). The Metro Storm Drain generally follows the historic Silver Bow Creek channel from below the Weed Concentrator to its confluence with Blacktail Creek. The Metro Storm Drain was constructed during the 1930s under a Works Progress Administration (WPA) program to provide a means of transporting water and mine wastes out of Butte in response to stream aggradation occurring during the early part of the century. The project consisted of realignment and filling of the original Silver Bow Creek drainage, which previously was a lowland swampy area with numerous mine waste ponds along its upper reach.

The upper reaches of Silver Bow Creek were truncated because of construction of the Berkeley Pit, which was initiated in 1955. Because of this, the entire flow of Silver Bow Creek was intercepted by the pit, a situation which is occurring today.

The upper Metro Storm Drain is typically dry, except during snowmelt or precipitation events. These conditions are monitored by a continuously recording weir operated by the U.S. Geological Survey below Continental Drive. The Clearwater Ditch (Figure 1-2) is routed into the Metro Storm Drain at its head. This ditch routes water from the western flanks of Rampart Mountain around the Berkeley Pit and into the Metro Storm Drain. The Clearwater Ditch is also typically dry except during snowmelt runoff events or during prolonged precipitation events. A channel also enters the head of the Metro Storm Drain from the Weed Concentrator complex. This channel has historically been used as a permitted discharge from the Barrel Ponds associated with the Weed Concentrator (Figure 1-2); there has been no evidence of discharge from the Barrel Ponds into the Metro Storm Drain since 1986 although water is currently contained in the ponds.

Several storm outfalls are directed into the Metro Storm Drain from below the Weed Concentrator to its confluence with Blacktail Creek. These outfalls drain various areas within Butte ranging from parking lot drains to major storm drain systems exiting waters from large areas on Butte Hill.

The Metro Storm Drain becomes a perennial surface water course near the middle reaches of the system. This is because the base of the Metro Storm Drain intercepts the shallow groundwater system in the area and serves as a linear drain. The quantity of flow measured in the Metro Storm Drain near its mouth during the Phase I Remedial Investigation (MultiTech, 1987) during non-runoff conditions was typically 0.4 to 0.5 cubic feet per second (cfs).

Blacktail Creek originates about 15 miles south of its confluence with the Metro Storm Drain in the Highland Mountains and drains approximately 75 square miles. Blacktail Creek is a perennial stream which supplies the majority of flow in modern day Silver Bow Creek. The USGS installed a continuously recording gaging station at the mouth of Blacktail Creek in October, 1988; this monitoring program is ongoing. Average flow in Blacktail Creek at its mouth since the gaging station was installed is 11.2 cubic feet per second (cfs).

For this report, the headwaters of Silver Bow Creek is defined as the confluence of the Metro Storm Drain and Blacktail Creek. Silver Bow Creek from its head to below the Colorado Tailings flows through an area which has been altered by man's activities. These alterations have resulted in a present day surface water course which has been rerouted from the historical location of the channel. Silver Bow Creek is confined within a series of manganese slag walls in the vicinity of the historic Butte Reduction Works area and has been redirected north of the Colorado Tailings through an excavated channel armored with riprap.

Within the lower part of Area I, storm outfalls enter Silver Bow Creek from the north near Montana Street and overland runoff moves directly into Silver Bow Creek from areas along the floodplain, including the Butte Reduction Works area and the Colorado Tailings. In addition, the Butte Metro Sewage Treatment Plant discharges treated effluent to Silver Bow Creek near the Colorado Tailings and Missoula Gulch enters the stream from the north just east of the Colorado Tailings.

The Butte Metro Sewage Treatment Plant discharge averages approximately 7.4 cfs and increases the average flow in Silver Bow Creek by about 30% (MultiTech, 1987). Missoula

Gulch is an intermittent stream which drains most of the west side of Butte. This drainage contributes little flow to Silver Bow Creek except during runoff conditions in Butte.

The USGS has operated a continuously recording gaging station on Silver Bow Creek just below the Colorado Tailings since 1984. Average flow measured at this station from 1983-1988 is 23.8 cfs; highest recorded flow was 424 cfs on May 25, 1987 and lowest recorded flow was 9.7 cfs on September 1 and September 5, 1988.

1.5.6 Groundwater Hydrology

Groundwater resources in the vicinity of Area I generally are associated with two water-bearing units. These include unconsolidated sediments associated with Tertiary and Quaternary aged valley fill overlying weathered and fractured bedrock units typically comprised of Tertiary aged quartz monzonite associated with the Boulder Batholith. The occurrence of groundwater in the unconsolidated valley fill is generally associated with laterally discontinuous coarse grained sand and gravel units. Depth to water in the unconsolidated valley fill ranges from two to over 30 feet. Well yields in the valley fill material typically range from less than five gallons per minute (gpm) to over 30 gpm.

Groundwater flow paths in the upper end of Area I near the Weed Concentrator are influenced by the presence of the Berkeley Pit. A groundwater divide is present in the unconsolidated material adjacent to the Metro Storm Drain. Groundwater north of this divide moves to the Berkeley Pit; groundwater movement south of the divide parallels the Metro Storm Drain.

Groundwater discharges to the lower reaches of the Metro Storm Drain from about Harrison Avenue to Blacktail Creek resulting in perennial flow in the lower half of the Metro Storm Drain. Vertical groundwater movement in the upper end of Area I is likely influenced by past dewatering activities associated with the Berkeley Pit. Water level data obtained at a well cluster near the upper end of the Metro Storm Drain indicates a downward gradient of approximately 3% to depths of approximately 150 feet (MultiTech, 1987). The measured downward component to groundwater movement in this area may indicate discharge of the shallow groundwater system into a deeper, more

permeable unit, possibly associated with the upper portion of the bedrock groundwater system.

Temporal trends in groundwater levels indicate a measurable water level decline in monitoring wells constructed in the vicinity of the Weed Concentrator. The decline of water levels appears to correlate with termination of operations at the Weed Concentrator when on-site process ponds were drained. The dropping water levels in this area may indicate the decline of a groundwater mound that was created by leakage from these ponds during active operations at the concentrator.

Groundwater movement in the lower reaches of Area I is generally parallel to but slightly toward Silver Bow Creek, indicative of gaining stream conditions. Discharge of groundwater into Silver Bow Creek was confirmed by synoptic flow measurements of Silver Bow Creek during the Phase I Remedial Investigation (MultiTech, 1987). Limited aquifer testing of groundwater-bearing zones 100 to 150 feet below ground surface completed during the Phase I Remedial Investigation (MultiTech, 1987) indicate low hydraulic conductivities, on the order of 10 to 30 gallons/day/square foot.

There has been minimal development of the water-yielding zones in the unconsolidated material in the Butte area as a water resource. This is primarily because most households and commercial businesses are supplied by a city-wide water distribution system, owned and operated by the Butte Water Company. Water for this system is derived from surface water sources located both within and outside of the Summit Valley. Recently, several households in Butte and the Butte/Silver Bow Government have begun installing irrigation wells which derive water from the unconsolidated material aquifer.

The quality of groundwater in the unconsolidated valley fill aquifers in Butte appears to be impacted by several sources of man-made contamination primarily associated with tailings deposits. Groundwater outside of the source areas is generally a calcium bicarbonate water; groundwater proximal to the source areas is a calcium sulfate type water (MultiTech, 1987). Concentrations of dissolved metals, including iron, zinc, copper, and cadmium in and near the source areas are up to four orders of magnitude higher than concentrations measured in groundwater located upgradient and cross gradient of identified source areas (MultiTech, 1987).

The occurrence of groundwater in the bedrock system both adjacent and subjacent to Area I is less clearly understood than the unconsolidated valley fill aquifers. Much of the bedrock groundwater system has been impacted by dewatering activities associated with historic mining activities at the Travona mine shaft, located near the west end of Butte, and at the Kelley mine shaft, located near the Berkeley Pit. Water pumped from these shafts lowered water levels in the bedrock system; the impact of dewatering activities at the Kelley shaft on the bedrock groundwater system is still realized today.

Groundwater in the bedrock system occurs in fractures and in weathered zones near the top of the rock package. Hydraulic characteristics of the bedrock system are poorly understood; it is probable that the system is complex because of the secondary permeability nature of materials hosting groundwater and because of the large network of underground mine shafts and tunnels located in bedrock underlying Butte.

There has been minimal development of bedrock groundwater resources in the Butte area owing both to impacts of shaft dewatering and because the area is serviced by the Butte Water Company. Pumping rates from Kelley shaft, when the pumping system was operational, were reported to be on the order of 5000 gpm (Hydrometrics, 1982). This provides some indication of the magnitude of groundwater movement through the bedrock system although a component of this discharge was probably derived from adjacent alluvial material.

The quality of groundwater in the bedrock system is variable and may be related to mineralogical zoning. Samples collected from several mine shafts located near the Berkeley Pit contain dissolved metals in concentrations which exceed primary and secondary drinking water standards (MBMG, 1988). Groundwater quality in the west camp of Butte (near the Travona Shaft) appears to be of much better quality; arsenic is the only parameter which exceeds primary drinking water standards (MBMG, 1988).

1.5.7 Land Use

Land use in the Area I Operable Unit is zoned by the Butte-Silver Bow government. The primary zoning classifications for Area I include residential and mining.

Several residences are located in Area I, particularly along the Metro Storm Drain. The City-County shop complex is located near the upper end of Area I. This facility covers a relatively large area and houses city equipment and offices. A large portion of the area along the Metro Storm Drain is currently unused probably because the area exhibits shallow groundwater and bogs.

The portion of Area I between Montana Street and the Colorado Tailings is typified by mine wastes, stockpiles of manganese, and light industry. Public access to the manganese stockpile area and the Butte sewage treatment plant is limited by chain-link fences and locked gates.

Access to the Colorado Tailings is primarily by foot; no easily accessible roads are routed to the exposed tailings. The area below the Colorado Tailings is used primarily for agricultural purposes; a corral is located in this area which temporarily confines livestock for slaughter at the Ranchland Packing Company.

Observations of dirt bike traffic and pedestrian traffic throughout Area I were made routinely during both the Phase I RI (MultiTech, 1987) and during the Phase II RI. On several occasions, children were observed playing and swimming in the Metro Storm Drain and in Silver Bow Creek. Because of the proximity of the operable unit to residential areas, Area I is used frequently by recreationists and workers alike.

1.6 PROJECT OBJECTIVES

Objectives to completing the Phase II RI at the Area I Operable Unit are described in the project sampling and analysis plan (CH2M HILL, 1989d). In general, objectives of the investigation were to obtain data necessary to evaluate the following:

- Areas that may be sources of windblown dust.
- The approximate areal and vertical extent of soil contamination.
- The approximate extent of groundwater contamination and the pathways of contaminant movement in the area's shallow groundwater systems.

- The impact of high flow on contaminant transport in the surface water system.

- The occurrence of organic compounds in the surface water system.

Other objectives to the investigation were to collect data to provide a basis for further characterization of the impact of exposed tailings/contaminated soils located within the operable unit on public health and the environment. Acquisition of soils data were deemed necessary to support a public health and environmental assessment of the operable unit and to evaluate various remedial alternatives for the area during the site feasibility study.

Based upon data gaps identified in CH2M HILL (1989c), four separate studies were completed to meet the stated project objectives. These included efforts to characterize surface water, groundwater, dispersed tailings, and impounded tailings.

Specific objectives for the various investigations completed during the Phase II RI included:

- Surface Water Investigation -- Objectives for completing a surface water investigation were to provide data to characterize the quality and parameter-specific loads in the study area's surface water during high flow conditions and to determine if organic contaminants are present in surface water during various flow regimes.

- Groundwater Investigation -- Objectives for completing a groundwater investigation in Area I were to: (1) collect sufficient data to determine the nature and extent of groundwater contamination within the study area vertically, areally, and seasonally; (2) better define pathways and hydraulics of contaminant movement in the area's groundwater system; and, (3) provide data to evaluate risks to public health.

- Dispersed Tailings/Contaminated Soils Sampling -- objectives for this work task were to: (1) characterize the nature and extent of dispersed contamination within the study area boundaries; (2) provide data to support a public health and environmental assessment for the operable unit; and, (3) provide data to

determine the impact of this contaminant source on receiving surface water and groundwater systems.

- Impounded Sources investigations -- Objectives for completing this work task were to: (1) determine the approximate volume of contaminated material associated with these deposits; (2) determine the nature of contamination associated with impounded deposits; and, (3) provide data to assess the impact of these deposits on groundwater and surface water resources and on air quality.

Determinations of the "nature and extent" of contamination in relation to groundwater, dispersed tailings/contaminated soils, and impounded tailings investigations were a somewhat subjective study objective. Precise definition of the nature and extent of contamination in Area I was not completed during this RI because of site complexities and because the size of the operable unit did not lend itself to this type of analysis at this juncture in the RI/FS process. A reasonable understanding of the nature, extent, and approximate volumes of contamination in soils and groundwater was acquired to support additional studies of the site. The study fell short of identifying specific locations exhibiting anomalous contaminant concentrations. This type of detailed site analysis (if necessary) will be completed at a later time.

SECTION 2.0 SURFACE WATER INVESTIGATION

2.0 SURFACE WATER INVESTIGATION

2.1 METHODS

This section provides a brief description of methods used to collect surface water samples during two sampling events completed during the Area I Operable Unit Phase II Remedial Investigation. Surface water sampling performed during the Phase II Remedial Investigation included sampling during a snowmelt event and during baseflow conditions in the area.

Figure 2-1 shows locations of surface water sampling stations utilized during the March 10, 1989 snowmelt sampling event in the Area I Operable Unit. Table 2-1 presents descriptions of sample site locations. Detailed descriptions of sampling sites are contained in Appendix A-1. The design of this sampling network allowed for characterization of the quality and flow characteristics of the surface water system entering, within, and exiting Area I. Only major storm outfalls to the Metro Storm Drain and Silver Bow Creek were sampled during the March 10, 1989 sampling episode; several other minor storm outfalls enter the primary water courses in the area.

The objective of field activities associated with the snowmelt sampling episode was to initiate sampling activities at each station during the rising limb of the snowmelt hydrograph and continue sampling though the peak and into the descending limb of the hydrograph. This situation occurred at several stations sampled; the hydrograph for stations above which there was a large drainage area did not exhibit a peak to the hydrograph during the time period in which these stations were sampled. Further discussion of this phenomenon is presented in Section 2.3.

During the snowmelt sampling event, field crews collected water samples every hour at each sample site. Field parameters, including pH, specific conductivity, and temperature were measured immediately following collection of each sample. Stream discharge was also measured every hour, coincident with sampling. Discharge was measured by using a current meter or by relating creek stage to rating curves established for those sites equipped with continuously recording gages.

TABLE 2-1

SURFACE WATER SAMPLE STATION LOCATIONS USED DURING MARCH 10, 1989 SNOWMELT RUNOFF SAMPLING

STATION NO.[1]	DESCRIPTION
SS-02	Metro Storm drain at head at USGS gaging station.
SS-03	Metro Storm drain near mouth; 200 feet west of Kaw Avenue.
SS-04	Blacktail Creek near mouth at USGS gaging station.
SS-06	Silver Bow Creek above Colorado Tailings.
SS-07	Silver Bow Creek below Colorado Tailings at USGS gaging station.
PS-02	Harrison Avenue storm sewer outfall near Civic Center.
PS-04	Missoula Gulch at mouth.
PS-05	Kaw Avenue storm sewer outfall near Montana Street.
PS-08	Butte Sewage Treatment Plant discharge.
PS-14	Drainage entering Metro Storm Drain from Weed Concentrator area - above Clearwater Ditch.
PS-15	Drainage on west end of Colorado Tailings to Silver Bow Creek.

[1] Station Locations shown on Figure 2-1.

Surface Water Features Map
Area I Operable Unit; Butte, Montana
FIGURE 2-1

Water quality samples were collected using a DH-48 sampler where adequate stream depth and discharge warranted use of this type of sampling device. At these stations, equal discharge sampling techniques were used. This method involved depth integrated sampling at four to six points in the stream cross section representing sections of equal stream discharge. Grab samples were collected at stations which were not conducive to depth and discharge integrated sampling techniques.

Collected samples were placed in ice-filled coolers for transport. Hourly samples collected from each station were then composited into a single sample. This procedure was completed by first calculating the volume of the entire runoff hydrograph for each sample site. The proportionate volume of the hydrograph that each hourly sample represented was then calculated. Each hourly sample was then partitioned utilizing a cone splitter to obtain a proportionate volume of sample which was representative of its relative percentage of the snowmelt hydrograph. These subsamples were then combined into a single sample set.

Following sample compositing, samples were filtered and preserved, as necessary, and prepared for shipment to an analytical laboratory. Samples were analyzed for common ions, selected nutrients, total suspended solids, and total, dissolved, and acid soluble metals. Table 2-2 summarizes the parameter list for surface water sampling completed during the Phase II Remedial Investigation. Sample preparation for acid soluble metal parameters was completed prior to sample shipment in accordance with the project sampling and analysis plan (CH2M HILL, 1989d).

One additional sample was collected at each station during the snowmelt sampling event for analysis of hexavalent chromium. This sample was collected at or near the peak of the hydrograph at each station. Because of the short holding time for analysis of this parameter (24 hours), these samples were shipped to an analytical laboratory immediately following sample collection via express mail. Therefore, hexavalent chromium analyses do not represent a composite of samples collected during the sampling event but rather provide a measure of concentrations at or near the peak of the snowmelt hydrograph.

Samples for analysis of contract laboratory program routine analytical services organic compounds were collected during or near peaks in the hydrographs at stations SS-03, SS-04, and SS-07 (Figure 2-1). Two samples were collected at each of these sites in accordance

TABLE 2-2

ANALYTICAL PARAMETER LIST FOR SURFACE WATER SAMPLING COMPLETED DURING THE AREA I PHASE II REMEDIAL INVESTIGATION

Metals*

Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc

Common Ions/Nutrients

Alkalinity
Chloride
Fluoride
Nitrite + Nitrate as N
Sulfate
TSS

CLP RAS Organics

Measured Field Parameters

pH
Specific Conductance
Temperature
Discharge

* RAS metals analyzed for total, acid soluble and dissolved constituents.

with methodologies described in the project sampling and analysis plan (CH2M HILL, 1989d). One sample at each station was collected from several points in cross section at the surface of the water and the other was a depth- and discharge-integrated sample collected from below the water surface. This sampling methodology provided a means to measure those compounds which may be floating on the water surface and those which may be travelling within the water profile as "sinkers."

Surface water samples were also collected during baseflow conditions for contract laboratory program routine analytical services organic analysis on August 21, 1989 (Table 2-2). Sampled sites were the same stations used for organic sampling during snowmelt runoff (SS-03, SS-04, and SS-07, Figure 2-1). Methods used to measure discharge and collect samples during this sampling event were identical to those described for runoff sampling with one exception. Grab samples were collected at station SS-03 in the Metro Storm Drain because the depth of water in the storm drain at the time of this sampling event was not sufficient for depth- and discharge-integrated sampling techniques.

Quality control samples were incorporated into the sample train during both sampling events in accordance with the project sampling and analysis plan (CH2M HILL, 1989d). These included duplicate samples (composites), cross-contamination blanks, bottle blanks, and blind field standards. Blind field standards were not available for hexavalent chromium and, hence, were not included with the sample shipment.

2.2 CHANGES TO THE PROJECT SAMPLING AND ANALYSIS PLAN

Two previously undesignated sampling stations identified in the project sampling and analysis plan (CH2M HILL, 1989d) were assigned station numbers during the snowmelt sampling event. These included station PS-14 (Figure 2-1) which represented the sample station located at the mouth of the drainage exiting the Weed Concentrator complex and PS-15 (Figure 2-1) which represented the station located at the west end of the Colorado Tailings. Station PS-15 monitored runoff from the Colorado Tailings which was concentrated in a rill prior to entry into Silver Bow Creek.

Two surface water runoff sampling events were scheduled in the project sampling and analysis plan (CH2M HILL, 1989d). The purpose of the second sampling event was to

collect runoff samples during a thunderstorm or frontal type rainfall event. Several attempts were made to sample storm runoff in Butte during spring and summer, 1989. The lack of sufficient precipitation over Area I during the time sampling crews were present resulted in a failed effort to complete this portion of the investigation. If, during the site feasibility study, it is decided this type of data is necessary, a separate effort will be completed to sample this type of runoff event.

2.3 PRESENTATION OF DATA/RESULTS

Discharge and inorganic water quality data resulting from the March 10, 1989 snowmelt runoff sampling event are presented in Appendix A-2. Organic compound water quality data from the March 10 and August 21, 1989 sampling events are contained in Appendix A-3.

2.3.1 Snowmelt Runoff Sampling Event

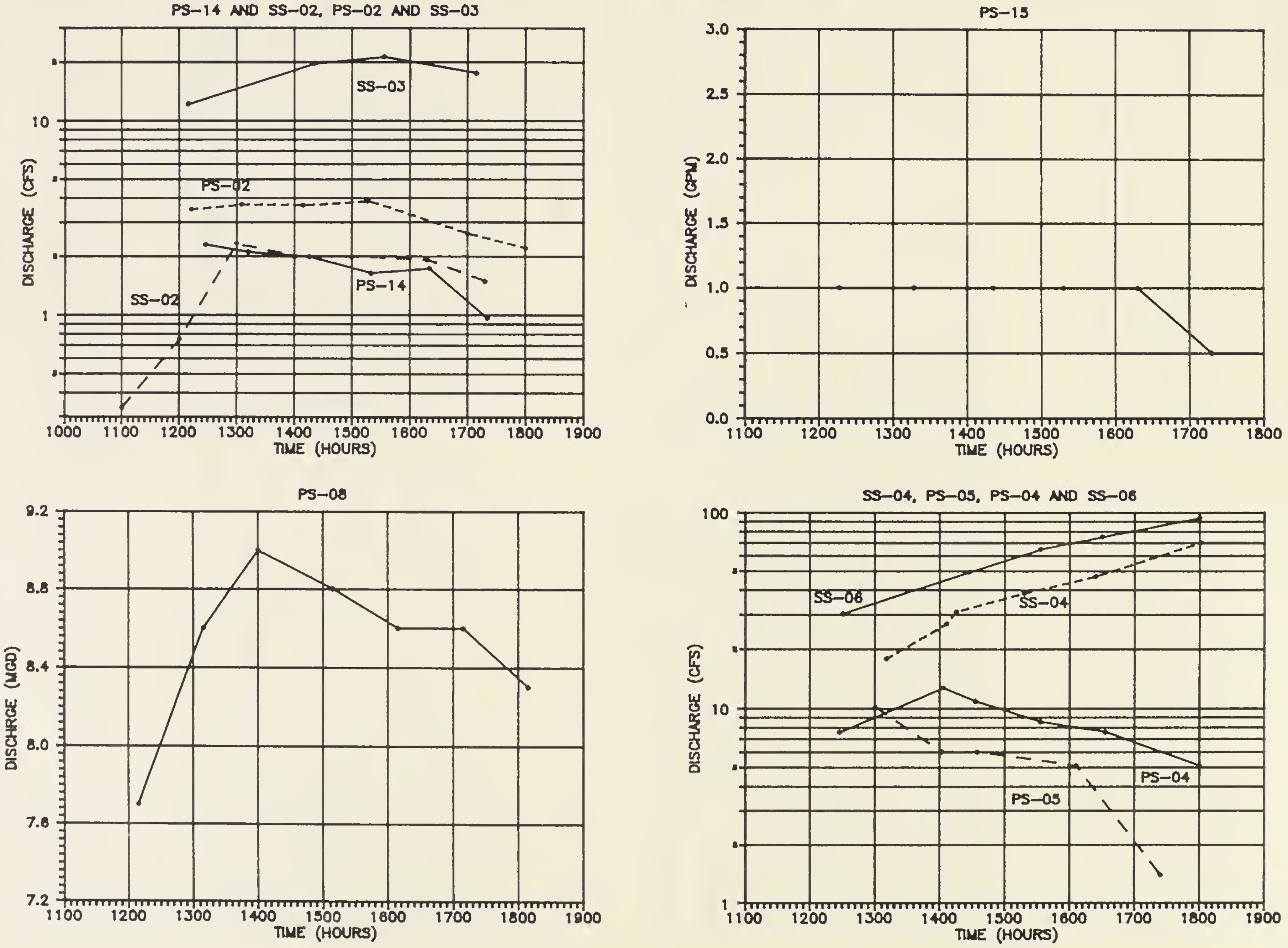
2.3.1.1 Discharge

Figure 2-2 illustrates hydrographs for the various sampling stations monitored during the March 10, 1989 snowmelt runoff sampling event. Discharge at most sites peaked by mid-afternoon and receded into the evening hours. Snowmelt hydrographs for stations SS-04 and SS-06 indicate that a peak in discharge did not occur during the time period during which sampling was completed. These stations are both mainstem sampling sites along Blacktail Creek and Silver Bow Creek, respectively.

Discharge data were not directly collected at station SS-07 (Figure 2-1) during the snowmelt sampling event. Instead, observations of creek stage were made at the adjacent USGS gaging station; these stage data were related to a rating curve established for the site by the USGS. In reviewing data from sites on Blacktail Creek and Silver Bow Creek during the snowmelt runoff event, a sizable discrepancy resulted in comparing flow data derived through use of the USGS rating curve at SS-07 to measured flows at stations located above SS-07, even after adding input flows between the stations. Because of this, loading data presented in subsequent sections for station SS-07 are based on the added flows of station SS-06 on Silver Bow Creek, the Sewage Treatment Plant effluent (PS-08), and the gaged flow off of the Colorado Tailings (PS-15) (Figure 2-1). Although it is recognized this

Hydrographs for Surface Water Stations

Monitored During March 10, 1989 Snowmelt Runoff Sampling Event



Area I Operable Unit Phase II Remedial Investigation

FIGURE 2-2

method of calculating flow for SS-07 is not precise, relative relationships in metals loads can be evaluated.

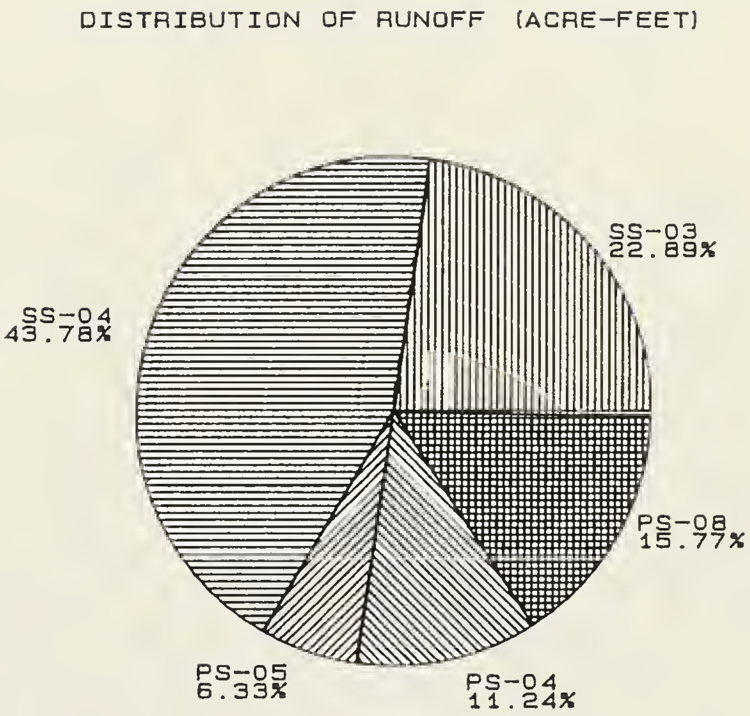
The hydrographs at sites SS-04 and SS-06 did not peak and recede like the other sites monitored during the snowmelt runoff event because of the large drainage area present above these gaging sites. Large drainage areas require a relatively longer period of time for snowmelt runoff occurring in the upper portions of the basin to enter lower reaches of the basin.

Figure 2-3 depicts the relative distribution of runoff volume between sampling stations during the snowmelt event for a common time period. Sampling stations illustrated on Figure 2-3 include those gaged inputs which directly enter Silver Bow Creek in the operable unit. Examination of Figure 2-3 indicates that approximately 43% of the gaged runoff volume was derived from Blacktail Creek (station SS-04). The next largest input was derived from the Metro Storm Drain (23% at station SS-03). Other monitored inputs from the Sewage Treatment Plant effluent (PS-08), Missoula Gulch (PS-04), and the Kaw Avenue storm drain (PS-05) made up the majority of the balance of runoff volume. The total volume of runoff gaged at mainstem sampling site SS-06 was within one percent of the sum of runoff volumes measured at these upstream sampling stations.

2.3.1.2 Water Quality

Figure 2-4 is a trilinear diagram of surface water sampling sites monitored during the March 10, 1989 snowmelt runoff sampling event. Figure 2-5 is a map showing a spatial distribution of stiff diagrams of common ions at sampled sites. Examination of Figure 2-4 indicates sampling stations PS-14, PS-15 and SS-02 group separately from other monitored sites as does station PS-08. Sampling stations PS-14 and SS-02 are located at the upper end of the Metro Storm Drain; station PS-15 monitored runoff from the Colorado Tailings (Figure 2-1). These stations exhibited a calcium sulfate type water with relatively large ion strength (Figure 2-5). Station PS-08 is the sewage treatment plant effluent; this water was a sodium bicarbonate type (Figure 2-5).

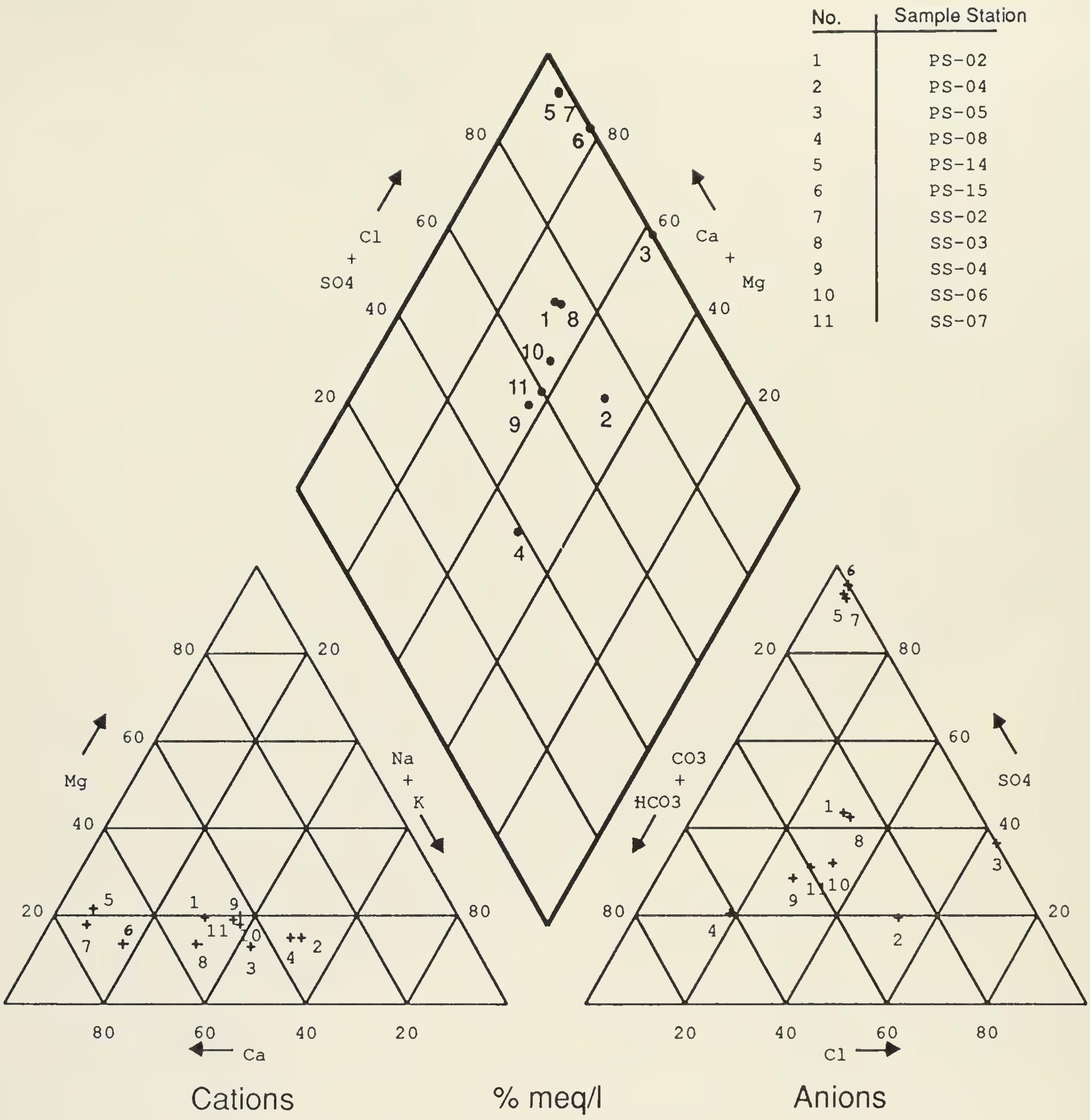
Runoff water from stations PS-02 (Harrison Avenue storm outfall), and SS-03 (Metro Storm Drain at its mouth) also exhibited a calcium sulfate type water. Runoff from Missoula



Sampling Station	Discharge (acre-feet)*
SS-04	74.82
PS-05	10.81
PS-04	19.21
PS-08	26.94
SS-03	39.12
PS-15	0.004

* From 1:30 p.m. to 5:00 p.m.

Distribution of Runoff Volume
During March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-3



Trilinear Diagram of Area I Surface Water
March 10, 1989 Snowmelt Runoff Sampling Event
FIGURE 2-4

Map Showing Stiff Diagrams of Surface Water Sampling Stations
March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-5

Gulch (PS-04) and from the Kaw Avenue storm outfall (PS-05) exhibited a sodium chloride type water which was somewhat unique with respect the type of water sampled at other sites during the runoff event. The preponderance of sodium chloride in water draining to these sampling sites may reflect transport of road sand-salt from the streets in Butte or a road sand stockpile area. No efforts were made to identify sources of this material in Butte.

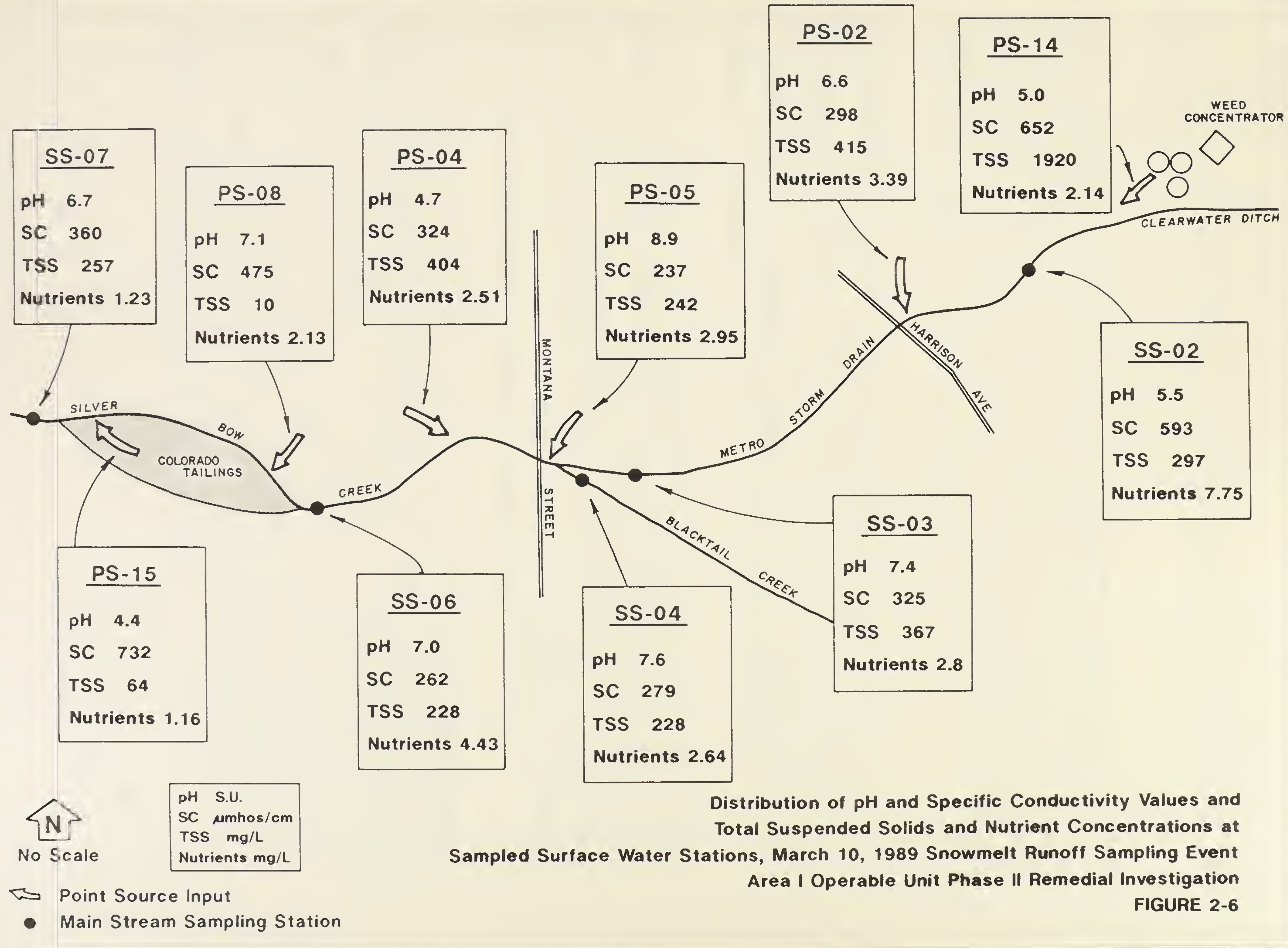
The type of water sampled in mainstem stations SS-04, SS-06, and SS-07 (Figure 2-1) did not change in a downstream direction during the snowmelt runoff event, even after the addition of different water types from several inputs along the course of Silver Bow Creek. Water at these stations remained a calcium bicarbonate type, presumably because the majority of flow in Silver Bow Creek during the runoff event was derived from Blacktail Creek.

Average values for specific conductance (SC), pH, total suspended solids (TSS) and nutrient concentrations are presented for each sampling location on Figure 2-6. Lowest pH values (5.0 s.u. or less) were measured at sampling sites monitoring runoff from the Weed Concentrator complex (PS-14); Missoula Gulch (PS-05); and the Colorado Tailings (PS-15). Mainstem sampling stations along Blacktail Creek and Silver Bow Creek indicated that pH decreased in a downstream direction during the snowmelt runoff event (7.6 s.u. at SS-04 to 6.7 s.u. at SS-07) (Figure 2-6).

Specific conductance values of samples obtained from the various surface water sampling sites monitored ranged from 237 to 732 umhos/cm @ 25° C. The largest values were measured at stations PS-14, PS-15, and SS-02 (Figure 2-6).

Total suspended solids (TSS) concentrations ranged from 10 to 1920 mg/L at sampled sites. Highest TSS concentrations occurred in water exiting the Weed Concentrator complex area (PS-14); the lowest TSS concentration occurred in discharge from the Sewage Treatment Plant (PS-08). TSS concentration in mainstem sampling stations SS-04, SS-06, and SS-07 were relatively consistent (Figure 2-6).

Nutrient concentrations (measured as nitrate + nitrite as N) ranged from 1.16 mg/L at PS-15 (runoff from the Colorado Tailings) to 7.75 mg/L at SS-02 (head of the Metro Storm



Distribution of pH and Specific Conductivity Values and Total Suspended Solids and Nutrient Concentrations at Sampled Surface Water Stations, March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-6

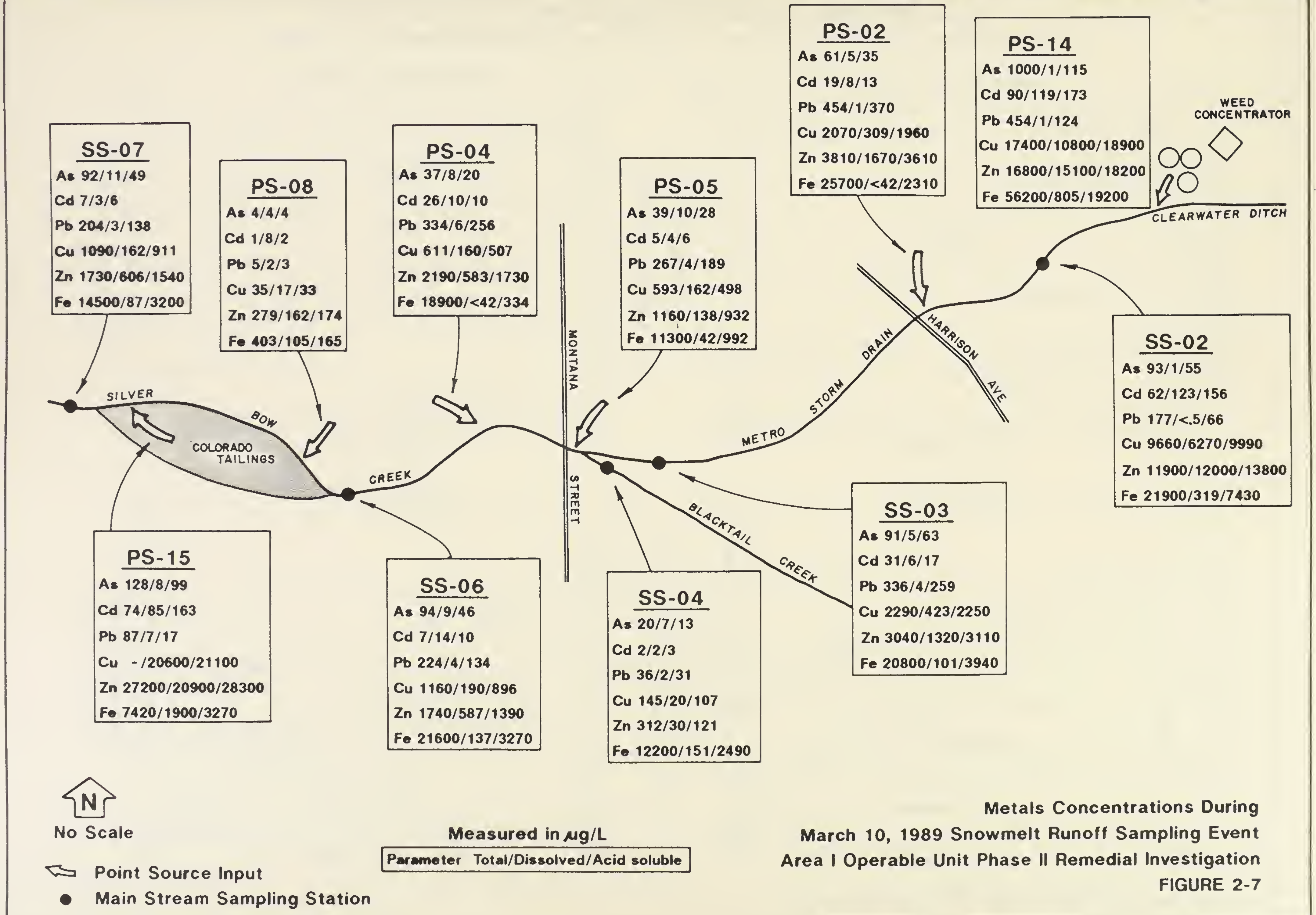
Drain) (Figure 2-6). Other monitored stations contained nutrient concentrations in the 2 to 4 mg/L range.

Figures 2-7 illustrates concentration data for total, dissolved, and acid soluble arsenic, cadmium, lead, copper, iron, and zinc for stations sampled during the snowmelt runoff event. Figure 2-8 contains plots of copper, zinc, and TSS concentrations and loadings at mainstem sampling sites SS-04 (Blacktail Creek) and SS-06 (Silver Bow Creek above the Colorado Tailings). Figure 2-9 presents loading data for total, dissolved, and acid soluble arsenic, cadmium, lead, copper, zinc, and iron for monitored stations.

Highest concentrations of total and acid soluble metals measured during the snowmelt runoff event generally occurred in water entering the Metro Storm Drain from the Weed Concentrator area (PS-14) and in runoff from the west end of the Colorado Tailings (PS-15) (Figure 2-7). The lowest measured concentrations of total and acid soluble metals occurred in discharge from Blacktail Creek and in the Sewage Treatment Plant effluent.

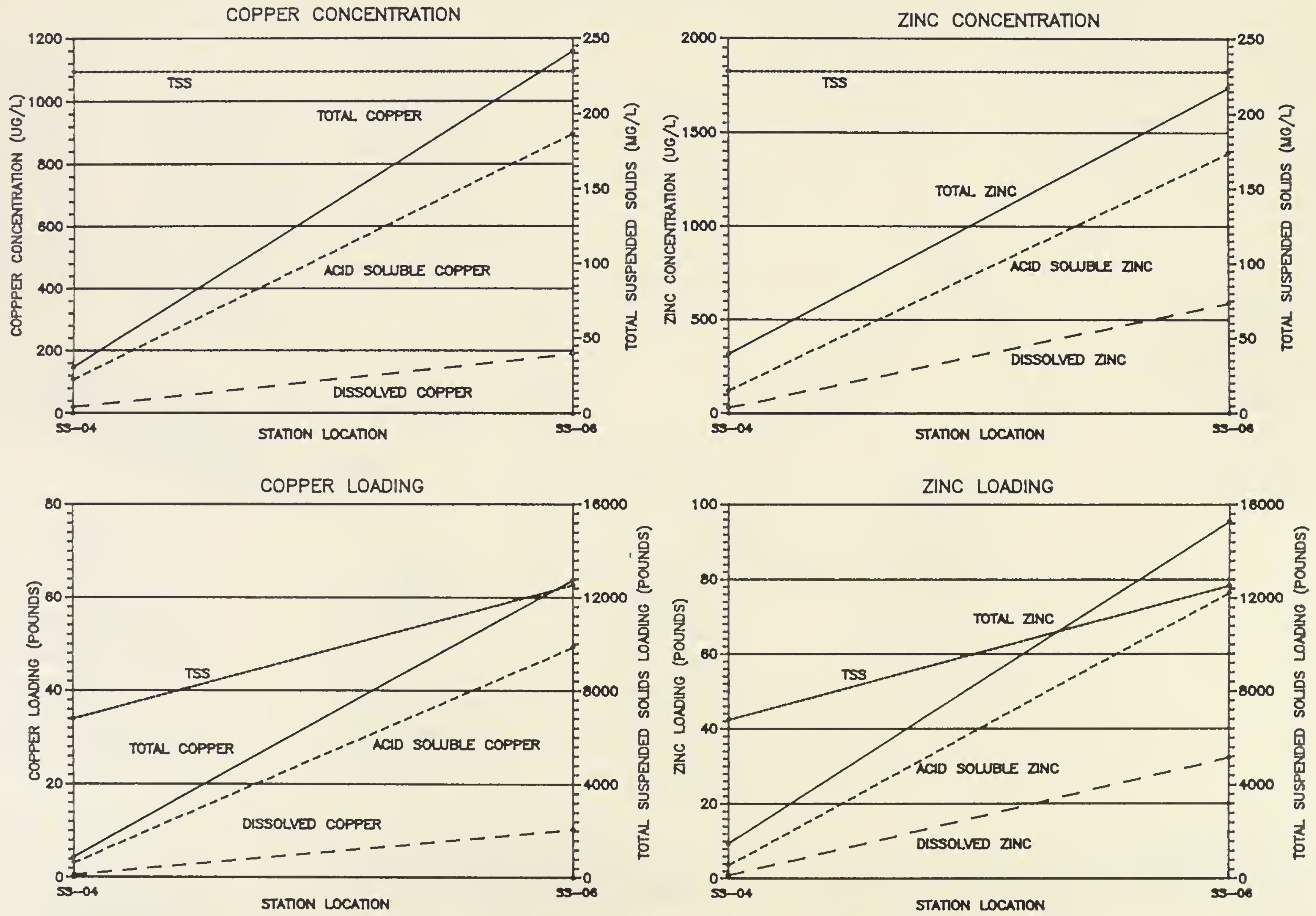
Metals data presented on Figure 2-7 suggest that arsenic, lead, and iron were generally transported through the surface water system during the snowmelt runoff event in the total fraction. Cadmium in the system during the runoff event was generally in the dissolved form. Copper and zinc were primarily carried in the dissolved fraction in the upper Metro Storm Drain area but appeared to precipitate out to the total fraction in the higher pH water in the lower Metro Storm Drain area and along Silver Bow Creek.

Total, dissolved, and acid soluble copper and zinc concentrations increased measurably between mainstem sampling sites SS-04 at the mouth of Blacktail Creek and SS-06 on Silver Bow Creek above the Colorado Tailings (Figure 2-8). TSS concentrations were generally similar between stations SS-04 and SS-06 (Figure 2-8). The primary reason for the measured increase in copper and zinc concentrations between SS-04 and SS-06 is input of metals-laden water from the Metro Storm Drain (SS-03) into Silver Bow Creek. The fact that TSS concentrations did not change significantly between the two sampling stations suggests that input concentrations of TSS from Blacktail Creek and the Metro Storm Drain and other inputs to Silver Bow Creek are relatively similar.



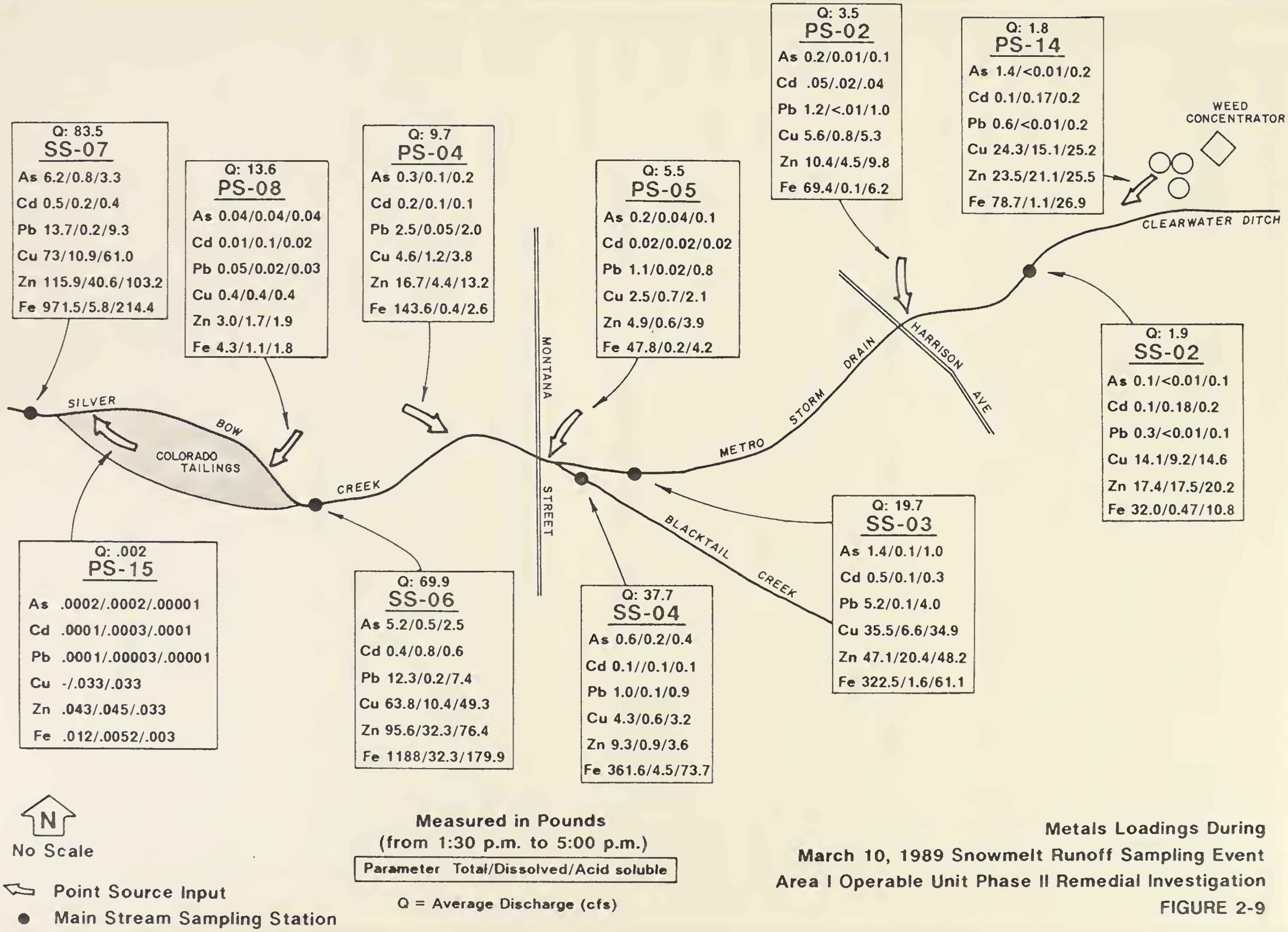
Metals Concentrations During
March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-7

Concentrations and Loads of Copper, Zinc and Total Suspended Solids at Main Stem Sampling Sites in Area I, March 10, 1989 Snowmelt Runoff Sampling Event



Area I Operable Unit Phase II Remedial Investigation

FIGURE 2-8



Metals Loadings During
March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-9

Metals loading numbers presented on Figures 2-8 and 2-9 represent the total metal-specific load which was transported by each station during a common three and one-half hour period for all stations sampled. Metal concentrations used in the loading calculations represent those measured in the composite sample collected at each sample station. Average discharge values used in the loading calculations were time weighted averages of instantaneous discharge measurements made during the snowmelt runoff event. This type of presentation of metals loads provides a means to evaluate parameter-specific loadings during a discrete time period; it does not represent the total load contributed during the entire snowmelt event.

Copper and zinc loads for total, dissolved, and acid soluble fractions and TSS increased in a downstream direction at mainstem sampling sites SS-04 and SS-06 (Figure 2-8). The rate of increase in copper and zinc loads was greatest for the total and acid soluble fractions as compared to the dissolved fractions. These trends indicate that the TSS entering Silver Bow Creek between Blacktail Creek and station SS-06, located above the Colorado Tailings contain elevated concentrations of copper and zinc as well as other metals. The primary sources of metals-laden TSS entering this reach of Silver Bow Creek include the Metro Storm Drain discharge and inputs from the Kaw Avenue storm drain and Missoula Gulch. Other unmeasured line and point source inputs may also add to the TSS concentrations entering the stream.

Figure 2-9 illustrates loads of arsenic, cadmium, lead, copper, zinc, and iron spatially at stations sampled during the snowmelt runoff event for a common time increment. In general, total metals loadings increased from the upper end of the Metro Storm Drain to below the Colorado Tailings (Figure 2-9). The largest point source load inputs to the Metro Storm Drain and Silver Bow Creek of total arsenic, copper, and zinc in the study area were derived from runoff from the Weed Concentrator area (PS-14). Missoula Gulch (PS-04) provided the greatest total lead and cadmium loads to the main stem surface water courses (2.54 pounds and 0.2 pounds, respectively).

In comparing total metals loads between mainstem sampling stations SS-02, SS-03, SS-06, and SS-07, the greatest load contributions of arsenic, lead, copper, zinc, and iron occurred between stations SS-03 and SS-06 (Figure 2-9). The greatest input of total cadmium load occurred between stations SS-02 and SS-03 which includes the Metro Storm Drain. The

next largest load increase of these metals was measured between stations SS-02 and SS-03, which generally bracket the Metro Storm Drain (Figure 2-9). The largest load increase of cadmium was measured between stations SS-02 and SS-03 (Figure 2-9). Acid soluble metals loads shown on Figure 2-9 exhibit these same general relationships.

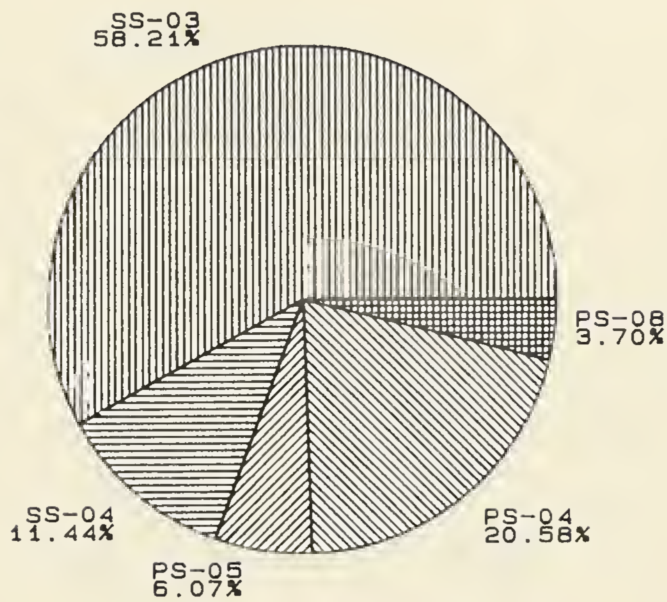
The distribution of load contribution to Silver Bow Creek during the snowmelt sampling event is shown on Figures 2-10, 2-11, and 2-12. These figures illustrate the relative distribution of total metals load as compared between sampling stations; the figures do not take into account deposition and other mass balance factors which affect sediment transport during runoff events. The illustrations indicate that relatively greater loads of total zinc, arsenic, cadmium, lead, and copper were derived from the Metro Storm Drain (SS-03) as compared to other inputs to Silver Bow Creek in Area I (Figures 2-10, 2-11, and 2-12). The majority of the iron load input to Silver Bow Creek was derived from Blacktail Creek (SS-04) and the Metro Storm Drain (SS-03) (Figure 2-10).

Analytical data indicate that numerous exceedances of both chronic and acute aquatic water quality criteria and both primary and secondary drinking water standards occurred at several stations sampled during the snowmelt runoff event in Area I. These exceedances are summarized in Table 2-3. Primary drinking water standards for arsenic, cadmium, and lead were measured at several stations sampled during the snowmelt runoff event. The most frequently exceeded aquatic water quality criteria exceedances at monitored stations were for either total or acid soluble cadmium, lead, copper and zinc.

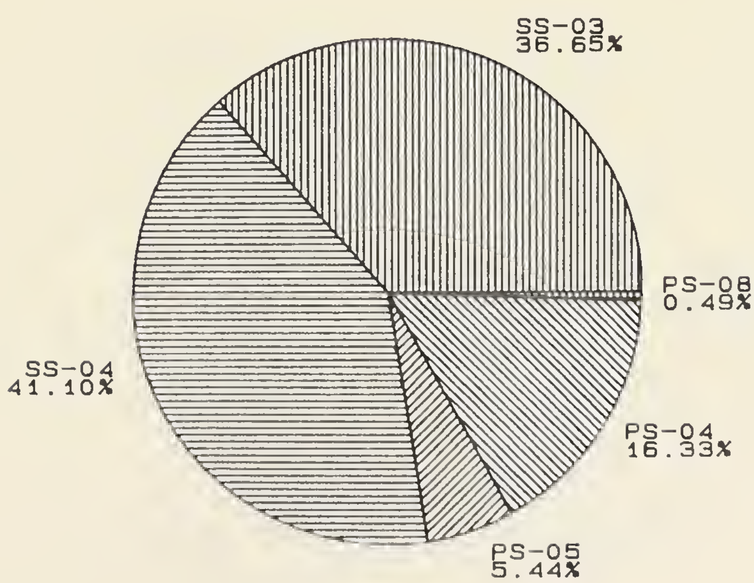
Hexavalent chromium concentrations in snowmelt runoff samples collected were all below 5 g/L, the analytical detection limit used during the analyses.

Organic data obtained during the snowmelt sampling event indicate most compounds analyzed were near or below their respective detection limits for Contract Laboratory Program Routine Analytical Services analyses. Organic compounds detected at the three stations sampled during the snowmelt runoff sampling event in Area I were primarily pesticides.

DISTRIBUTION OF ZINC LOADING

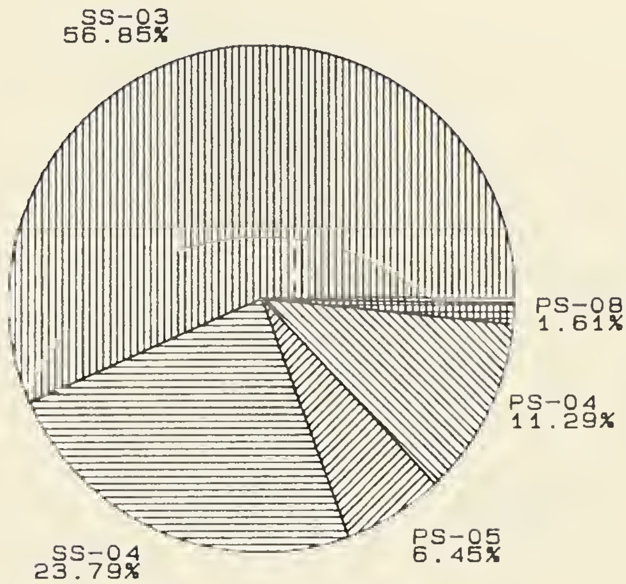


DISTRIBUTION OF IRON LOADING

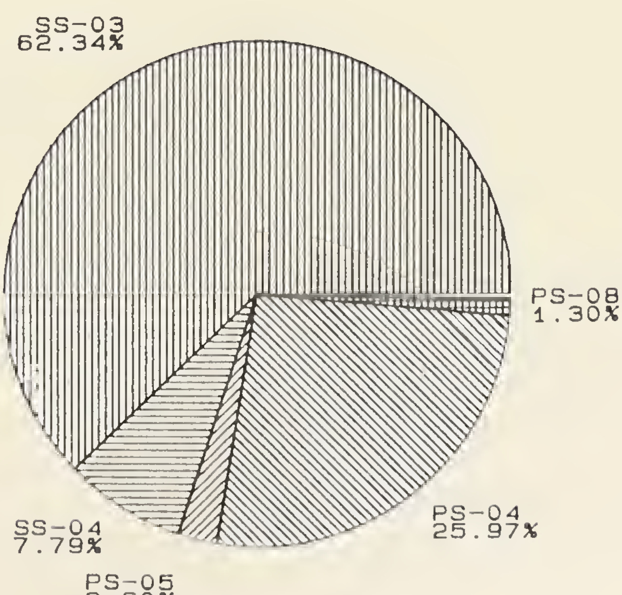


Distribution of Zinc and Iron Loadings
During March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-10

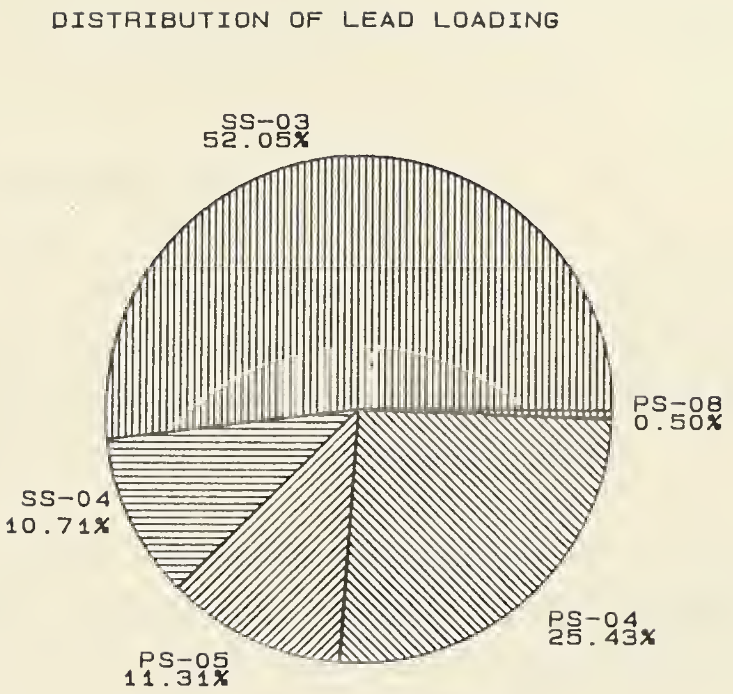
DISTRIBUTION OF ARSENIC LOADING

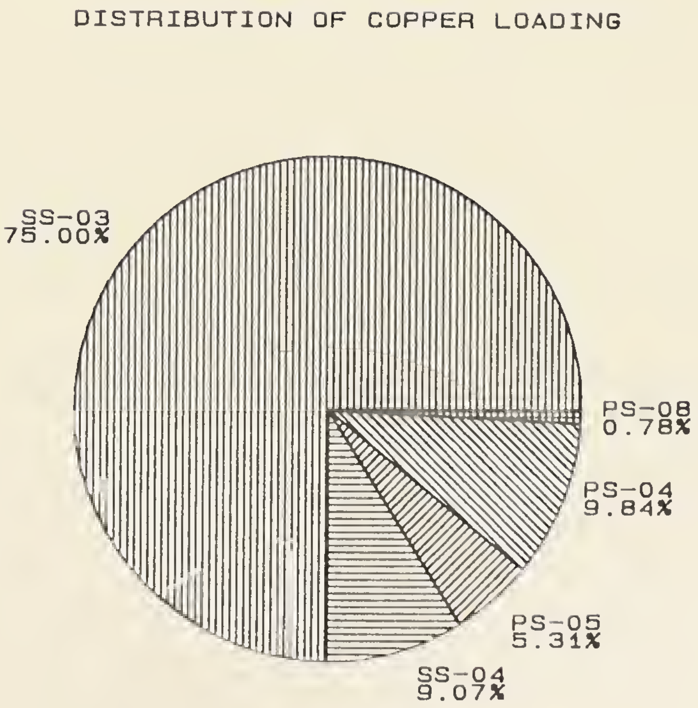


DISTRIBUTION OF CADMIUM LOADING



Distribution of Arsenic and Cadmium Loadings
During March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-11





Distribution of Lead and Copper Loadings
During March 10, 1989 Snowmelt Runoff Sampling Event
Area I Operable Unit Phase II Remedial Investigation
FIGURE 2-12

Measured concentrations of detected organic compounds in collected samples did not exceed any established drinking water standards or health advisories. The data also indicate that compounds detected in samples collected from the water surface were generally also detected in samples collected from below the water surface.

2.3.2 Low Flow Sampling Event

Low flow sampling was completed on August 21, 1989 at sampling stations SS-03, SS-04, and SS-07. The intent of sampling organic compounds during these flow conditions was to determine if sources of organic contamination derived from groundwater inflow or other sources could be identified in the area's surface water courses.

Analytical data resulting from low flow sampling completed in Area I during the Phase II Remedial Investigation indicate organic compounds detected were generally similar to those detected during the snowmelt runoff event and included mostly pesticides. Measured concentrations of detected compounds in collected samples did not exceed established drinking water standards or health advisories. The data also indicate that compounds detected in samples collected from the water surface were generally also detected in samples collected from below the water surface.

TABLE 2-3

SUMMARY OF AQUATIC AND DRINKING WATER
EXCEEDANCES; AREA I OPERABLE UNIT
MARCH 10, 1989 SNOWMELT RUNOFF EVENT

EXCEEDANCES
(Y = YES; N = NO; N/A = NOT APPLICABLE)

STATION[1]	PARAMETER	CHRONIC[2]	ACUTE[3]	MCL[4]	SMCL[5]	STATION[1]	PARAMETER	CHRONIC[2]	ACUTE[3]	MCL[4]	SMCL[5]	STATION[1]	PARAMETER	CHRONIC[2]	ACUTE[3]	MCL[4]	SMCL[5]
SS-02	As	N	N	Y	N/A	SS-03	As	N	N	Y	N/A	SS-04	As	N	N	N	N/A
	Cd	Y	Y	Y	N/A		Cd	Y	Y	Y	N/A		Cd	Y	N	N	N/A
	Pb	Y	Y	Y	N/A		Pb	Y	Y	Y	N/A		Pb	Y	Y	N	N/A
	Cr	N/A	N/A	N	N/A		Cr	N/A	N/A	Y	N/A		Cr	N/A	N/A	N	N/A
	Cr VI	N	N	N/A	N/A		Cr VI	N	N	N/A	N/A		Cr VI	N	N	N/A	N/A
	Cu	Y	Y	N/A	Y		Cu	Y	Y	N/A	Y		Cu	Y	Y	N/A	N
	Fe	N/A	N/A	N/A	Y		Fe	N/A	N/A	N/A	Y		Fe	N/A	N/A	N/A	Y
	Zn	Y	Y	N/A	Y		Zn	Y	Y	N/A	N		Zn	Y	Y	N/A	N
	Mn	N/A	N/A	N/A	Y		Mn	N/A	N/A	N/A	Y		Mn	N/A	N/A	N/A	Y
SS-06	As	N	N	Y	N/A	SS-07	As	N	N	Y	N/A	PS-02	As	N	N	Y	N/A
	Cd	N	N	N	N/A		Cd	N	N	N	N/A		Cd	Y	N	Y	N/A
	Pb	Y	Y	Y	N/A		Pb	Y	Y	Y	N/A		Pb	Y	Y	Y	N/A
	Cr	N/A	N/A	N	N/A		Cr	N/A	N/A	N	N/A		Cr	N/A	N/A	N	N/A
	Cr VI	N	N	N/A	N/A		Cr VI	N	N	N/A	N/A		Cr VI	N	N	N/A	N/A
	Cu	Y	Y	N/A	Y		Cu	Y	Y	N/A	Y		Cu	Y	Y	N/A	Y
	Fe	N/A	N/A	N/A	Y		Fe	N/A	N/A	N/A	Y		Fe	N/A	N/A	N/A	Y
	Zn	Y	Y	N/A	N		Zn	Y	Y	N/A	N		Zn	Y	Y	N/A	N
	Mn	N/A	N/A	N/A	Y		Mn	N/A	N/A	N/A	Y		Mn	N/A	N/A	N/A	Y
PS-04	As	N	N	N	N/A	PS-05	As	N	N	N	N/A	PS-08	As	N	N	N	N/A
	Cd	Y	N	Y	N/A		Cd	N	N	N	N/A		Cd	N	N	N	N/A
	Pb	Y	Y	Y	N/A		Pb	Y	Y	Y	N/A		Pb	Y	N	N	N/A
	Cr	N/A	N/A	N	N/A		Cr	N/A	N/A	N	N/A		Cr	N/A	N/A	N	N/A
	Cr VI	N	N	N/A	N/A		Cr VI	N	N	N/A	N/A		Cr VI	N	N	N/A	N/A
	Cu	Y	Y	N/A	N		Cu	Y	Y	N/A	N		Cu	Y	Y	N/A	N
	Fe	N/A	N/A	N/A	Y		Fe	N/A	N/A	N/A	Y		Fe	N/A	N/A	N/A	Y
	Zn	Y	Y	N/A	N		Zn	Y	Y	N/A	N		Zn	Y	Y	N/A	N
	Mn	N/A	N/A	N/A	Y		Mn	N/A	N/A	N/A	Y		Mn	N/A	N/A	N/A	Y

TABLE 2-3 continued

STATION[1]	PARAMETER	CHRONIC[2]	ACUTE[3]	MCL[4]	SMCL[5]
PS-14	As	Y	Y	Y	N/A
	Cd	Y	Y	Y	N/A
	Pb	Y	Y	Y	N/A
	Cr	N/A	N/A	N	N/A
	Cr VI	N	N	N/A	N/A
	Cu	Y	Y	N/A	Y
	Fe	N/A	N/A	N/A	Y
	Zn	Y	Y	N/A	Y
	Mn	N/A	N/A	N/A	Y

STATION[1]	PARAMETER	CHRONIC[2]	ACUTE[3]	MCL[4]	SMCL[5]
PS-15	As	N	N	Y	N/A
	Cd	Y	Y	Y	N/A
	Pb	Y	N	Y	N/A
	Cr	N/A	N/A	N	N/A
	Cr VI	N	N	N/A	N/A
	Cu	Y	Y	N/A	Y
	Fe	N/A	N/A	N/A	N
	Zn	Y	Y	N/A	Y
	Mn	N/A	N/A	N/A	Y

[1] Sample station locations shown on Figure 2-1.

[2] Freshwater chronic water quality criteria - hardness dependent. From U.S. EPA (1986)

[3] Freshwater acute water quality criteria - hardness dependent. From U.S. EPA (1986).

[4] Drinking water maximum contaminant level. From 40 CFR Part 141, Dec., 1975.

[5] Drinking water secondary maximum contaminant level. From 40 CFR Part 143, July, 1979.

SECTION 3.0 GROUNDWATER INVESTIGATION

3.0 GROUNDWATER INVESTIGATION

3.1 METHODOLOGY

This section presents brief descriptions of methodologies used to complete various components of the Phase II Remedial Investigation groundwater study. In general, study methods utilized at the site were consistent with procedures described in the project sampling and analysis plan (CH2M HILL, 1989d). Deviations to field methods described in the project sampling and analysis plan resulting from completion of the Phase II Remedial Investigation are described in Section 3.2.

3.1.1 Surface Geophysical Investigation

A surface geophysical investigation was completed in the Area I Operable Unit using a Bison Model 2390-T-50 transmitter and the Model 2390-R receiver earth resistivity system. Electrical resistivity surveying is a geophysical technique that measures apparent earth resistivity from the ground surface. Because various types of earth materials exhibit certain characteristic resistivity values, they can be distinguished from one another. Surface resistivity testing is also suited to locating groundwater and to identifying spatial changes of the specific electrical conductivity of shallow groundwater.

The objective in completing a resistivity survey in Area I was to better define lateral and vertical changes in site lithology and groundwater conditions to provide a basis for siting groundwater monitoring wells. Field crews completed the resistivity survey at several sites within Area I. At each survey site, a sounding was completed using a Wenner array. This type of array defines the spacing requirements ("A" spacing) for both current electrodes and the potential electrodes as being equi-distant from each other. Apparent resistivity measurements were initially obtained at each site using a probe spacing of one to two feet. The spacing of the probes was then expanded outward from the sounding site incrementally and measurements of apparent resistivity were obtained at each increment. Resultant field data were entered into a field book; field plots of collected data were made on logarithmic paper to determine if additional soundings were necessary at each site to fill identified data gaps or to better define trends in the data.

Figure 3-1 shows locations and orientations of resistivity sounding sites used during the Phase II Remedial Investigation. Selected locations provided for adequate spatial distribution to provide data from throughout the study area and also focused data collection in areas exhibiting anomalous data. Sounding orientations and maximum probe spacings associated with the resistivity survey were often dictated by the presence of structures and utilities.

3.1.2 Monitoring Well Installation

Groundwater monitoring wells were installed at 28 locations in the Area I Operable Unit during the Phase II Remedial Investigation (Exhibit I). Paired monitoring wells were installed at 14 of the 28 well sites to determine the vertical variability of both groundwater chemistry and water levels. Paired well completions involved installation of two monitoring wells at the same site which were screened and completed at different depths.

Locations of monitoring wells installed during the Phase II Remedial Investigation were selected in consideration of the following:

- surface resistivity data,
- locations of existing monitoring wells,
- the need to collect data spatially throughout the study area,
- the need to characterize groundwater in the deep (>200 feet) groundwater-bearing units near the City-County shop complex, and
- the desire to establish cross sections of wells normal to the Metro Storm Drain and Silver Bow Creek.

Monitoring wells were installed using three types of drill rigs. These included an auger rig, a cable tool rig, and an air rotary rig. Auger drill rigs were used to install shallow monitoring wells in areas where the subsurface material was relatively easy to penetrate. This generally included the area west of Montana Street in the vicinity of the Butte

Locations and Orientations of Surface Resistivity Sounding Sites;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-1

Reduction Works tailings impoundments and the Colorado Tailings. The cable tool and air rotary drill rigs were used to install deeper wells in the Colorado Tailings area and wells throughout the remainder of the site.

Monitoring wells installed during the Phase II Remedial Investigation were constructed in accordance with the following protocol:

- The drill rig and all downhole equipment were cleaned initially with a portable steam cleaner and brush.

- The borehole was then advanced. Split-spoon samples were collected periodically at zones of interest in certain boreholes. Drill cuttings were monitored continuously and described on field forms. Observations of quantities of water encountered and corresponding depths were also recorded on field forms. Samples of formation water were periodically obtained during borehole advancement and field analyzed for temperature, pH, and specific conductivity.

- Temporary steel casing with a drive shoe was advanced with the drill bit when the cable tool and air rotary drill rigs were utilized. This served to maintain borehole integrity in the unconsolidated sediments and precluded the need for drilling fluids and muds. When the auger drill rig was used, hollow-stem flight augers were advanced with the borehole to maintain borehole integrity.

- When the target depth of the borehole was achieved, decontaminated PVC casing was inserted into the borehole. Factory slotted screened sections of PVC were incorporated into the casing column adjacent to the targeted water-bearing zone.

- Chemically inert Colorado silica sand was inserted into the annular space between the temporary steel casing and the PVC casing from the total depth of the borehole to a depth several feet above the screened section of the monitoring well. An approximately one foot thick layer of quarter-inch bentonite pellets was inserted into the well annulus above the sand pack. The remaining annular space was filled with either a bentonite slurry or bentonite chips to

approximately two feet below ground surface. As all of these materials were added to the well annulus, the temporary steel casing was pulled out of the borehole at a rate coincident with the volume of annular space backfilled.

The temporary steel casing was eventually pulled completely out of the borehole. Precautions were taken to make certain there was sufficient overlap between the temporary steel casing and the backfilled material to preclude gaps in the backfill sequence.

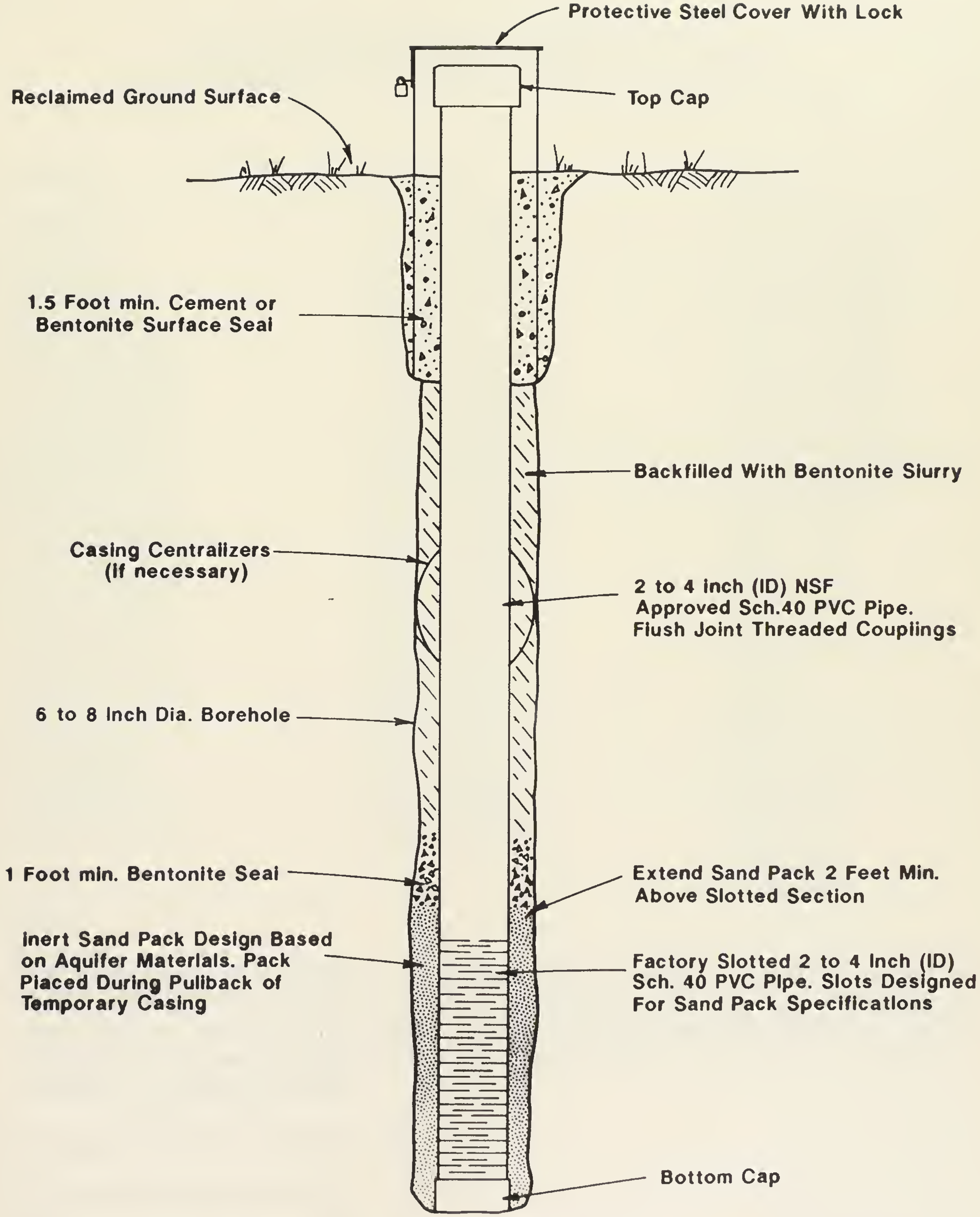
- Monitoring wells were completed by installing a locking well protector over the PVC casing. The well protector was grouted into the ground about the well to a depth of 1.5 to two feet. The well was secured with a lock after appropriate notations were made on the inside of the well protector cap denoting well number, depth, etc. Figure 3-2 is a schematic of a typical monitoring well installed during the Area I Operable Unit Phase II Remedial Investigation.

- Upon completion of monitoring well installations, each well was developed using a surge block and a hand-lift pump or bailer to remove drilling debris from the well and to insure adequate communication between the aquifer and the well. Field forms were filled out in conjunction with well development to document the status of the well during the development process.

3.1.3 Groundwater Sampling

Monitoring wells installed during the Phase I and Phase II Remedial Investigations were sampled during August and November, 1989. Several other existing monitoring wells and domestic wells were also sampled in conjunction with the August and November sampling event. Table 3-1 lists wells sampled during August and November, 1989; Exhibit I shows locations of these wells.

Monitoring wells were sampled by first evacuating at least three bore volumes from each well utilizing a decontaminated hand-lift pump in accordance with standard operating procedures described in the project sampling and analysis plan (CH2M HILL, 1989d). Field parameters including temperature, pH, and specific conductivity were monitored for



Schematic of Typical Monitoring Well Construction;
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-2

TABLE 3-1

SUMMARY OF WELLS SAMPLED DURING AUGUST AND NOVEMBER, 1989 SAMPLING EVENTS AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Well No. [1]	Well No. [1]	Well No. [1]
AI-DW-01[2]	AI-GW-GS-22[2]	AI-GW-GS-41S[2]
AI-DW-02[2]	AI-GW-GS-23[2]	AI-GW-GS-42D[2]
AI-DW-03[3]	AI-GW-GS-24D[2]	AI-GW-GS-42S[2]
AI-GW-GS-07[2]	AI-GW-GS-24S[2]	AI-GW-GS-43D[2]
AI-GW-GS-08[2]	AI-GW-GS-25[2]	AI-GW-GS-43S[2]
AI-GW-GS-09[2]	AI-GW-GS-26[2]	AI-GW-GS-44D[2]
AI-GW-GS-10D[2]	AI-GW-GS-27D[2]	AI-GW-GS-44S[2]
AI-GW-GS-10S[2]	AI-GW-GS-27S[2]	AI-GW-GS-45[2]
AI-GW-GS-11[2]	AI-GW-GS-28[2]	AI-GW-GS-46D[2]
AI-GW-GS-12[2]	AI-GW-GS-29D[2]	AI-GW-GS-46S[2]
AI-GW-GS-13A[4]	AI-GW-GS-29S[2]	AI-GW-GS-50[2]
AI-GW-GS-13B[3]	AI-GW-GS-30D[2]	AI-PW-04[3]
AI-GW-GS-14[2]	AI-GW-GS-30S[2]	AMC - 12[3]
AI-GW-GS-15D[2]	AI-GW-GS-31D[2]	AMC - 13[2]
AI-GW-GS-15S[2]	AI-GW-GS-31S[2]	AMC - 23[3]
AI-GW-GS-16[2]	AI-GW-GS-32[2]	AMC - 24[3]
AI-GW-GS-17D[2]	AI-GW-GS-33[2]	W-01[3]
AI-GW-GS-17S[2]	AI-GW-GS-34D[2]	MP-07[3]
AI-GW-GS-18[2]	AI-GW-GS-34S[2]	MF-04[3]
AI-GW-GS-19[2]	AI-GW-GS-35D[2]	BMW-4A[3]
AI-GW-GS-20[2]	AI-GW-GS-35S[2]	BMW-4B[3]
AI-GW-GS-21D[2]	AI-GW-GS-40[2]	BMW-4T[3]
AI-GW-GW-21S[2]	AI-GW-GS-41D[2]	BMW-6B[3]
		BMW-10A[3]
		CT-84-10[3]

NOTES:

[1] Well locations shown on Exhibit I. "S" denotes shallower completion, and "D" denotes deeper completion at same site. For well AI-GW-GS-13, "A" denotes deeper completion and "B" denotes shallower completion at same site. Well Nos. AI-GW-GS-07 through AI-GW-GS-15 are Phase I RI wells. Well Nos. AI-GW-GS-16 through AI-GW-GS-50 and AI-PW-04 are Phase II RI wells.

[2] Sampled August and November, 1989

[3] Sampled November, 1989 only

[4] Sampled August, 1989 only

consistency during the evacuation process. Groundwater samples were collected following removal of at least three bore volumes of water and when measured field parameters varied by less than 5% for three consecutive measurements of evacuated water.

A decontaminated PVC bailer was then lowered into the well to obtain a sample. The extracted sample was transferred into appropriate sample containers. The sample collected for dissolved metals analysis was field filtered through a 0.45 micron filter prior to placement into the sample container in accordance with the project sampling and analysis plan (CH2M HILL, 1989d). Samples were field preserved, as appropriate, and placed into coolers. Field parameters, including temperature, pH, Eh, and specific conductivity were measured immediately upon sample retrieval and recorded on field forms.

Necessary paperwork was completed in the field in accordance with the project sampling and analysis plan. Sample coolers and corresponding paperwork were then shipped to appropriate laboratories for analysis. Table 3-2 summarizes parameters analyzed in groundwater samples collected during the August and November, 1989 sampling events.

3.1.4 Water Level Monitoring

Water levels in monitoring wells were monitored on a monthly basis in the Area I Operable Unit from August, 1989 through January, 1990. Wells included in the water level monitoring program were those wells installed during the Phase I and Phase II Remedial Investigations and selected other monitoring and domestic wells. Table 3-3 lists wells monitored for water levels within the Area I Operable Unit. Exhibit I shows locations of these wells.

Water level measurements were made with an electric well probe to a known measuring point on the well casing. The measuring point typically used during the investigation was the northern quadrant of the top of the steel well protector. The electric well probe was calibrated during each measurement episode to a steel tape. Measurements were made to the nearest hundredth of a foot and entered into a project field book. Collected data were input to the project data base management system.

TABLE 3-2

ANALYTICAL PARAMETER LIST FOR AUGUST AND NOVEMBER, 1989
GROUNDWATER SAMPLING COMPLETED DURING
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Laboratory Parameters	Field Parameters
Aluminum	Static Water Level
Antimony	Temperature
Arsenic	Specific Conductivity
Barium	pH
Beryllium	Eh
Cadmium	
Calcium	
Chromium	
Cobalt	
Copper	
Iron	
Lead	
Magnesium	
Manganese	
Mercury*	
Nickel	
Potassium	
Selenium	
Silver	
Sodium	
Thallium	
Vanadium	
Zinc	
Chloride	
Fluoride	
Nitrate + Nitrate as N	
Sulfate	
Total Alkalinity	

Note: Metals parameters analyzed as dissolved fraction.
* August sampling event only

TABLE 3-3

MEASURING POINT ELEVATIONS OF WELLS
INCLUDED IN WATER LEVEL MONITORING PROGRAM
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Well No.	Measuring Point Elevation (Ft. AMSL)[1]	Well No.	Measuring Point Elevation (Ft. AMSL)[1]
AI-GW-GS-07	5479.39	AI-GW-GS-31S	5451.64
AI-GW-GS-08	5458.02	AI-GW-GS-32	5450.80
AI-GW-GS-09	5457.70	AI-GW-GS-33	5474.90
AI-GW-GS-10D	5477.43	AI-GW-GS-34D	5434.51
AI-GW-GS-10S	5477.43	AI-GW-GS-34S	5434.57
AI-GW-GS-11	5457.38	AI-GW-GS-35D	5465.56
AI-GW-GS-12	5442.67	AI-GW-GS-35S	5466.61
AI-GW-GS-13A	5441.15	AI-GW-GS-40	5481.30
AI-GW-GS-13B	5440.64	AI-GW-GS-41D	5491.34
AI-GW-GS-14	5455.23	AI-GW-GS-41S	5491.88
AI-GW-GS-15D	5445.28	AI-GW-GS-42D	5471.11
AI-GW-GS-15S	5445.28	AI-GW-GS-42S	5471.37
AI-GW-GS-16	5440.37	AI-GW-GS-43D	5474.98
AI-GW-GS-17D	5434.10	AI-GW-GS-43S	5475.04
AI-GW-GS-17S	5434.71	AI-GW-GS-44D	5476.24
AI-GW-GS-18	5439.08	AI-GW-GS-44S	5476.24
AI-GW-GS-19	5445.26	AI-GW-GS-45	5490.86
AI-GW-GS-20	5457.20	AI-GW-GS-46D	5484.03
AI-GW-GS-21D	5447.75	AI-GW-GS-46S	5483.76
AI-GW-GS-21S	5447.61	AI-GW-GS-50	5475.70
AI-GW-GS-22	5435.91	AI-DW-01	5481.81
AI-GW-GS-23	5437.16	AI-DW-02	5499.46
AI-GW-GS-24D	5433.54	AI-PW-04	5427.97
AI-GW-GS-24S	5434.10	AMC-6	5493.36
AI-GW-GS-25	5427.76	AMC-8	5525.61
AI-GW-GS-26	5425.67	AMC-12	5480.10
AI-GW-GS-27D	5418.99	AMC-13	5475.28
AI-GW-GS-27S	5419.91	AMC-23	5448.29
AI-GW-GS-28	5446.34	AMC-24	5452.06
AI-GW-GS-29D	5443.22	MP-04	
AI-GW-GS-29S	5443.26	NE-2	5435.12
AI-GW-GS-30D	5456.25	BMW-4A	5418.25[2]
AI-GW-GS-30S	5456.52	BMW-4B	5419.34[2]
AI-GW-GS-31D	5451.80	BMW-4T	5418.93[2]

NOTES:

(1) Measuring point is top of steel well protector, north quadrant. AMSL = above mean sea level. U.S. Geological Survey datum. Well locations shown on Exhibit I.

(2) Measuring point is top of PVC casing. ARCO Coal Company survey data.

3.1.5 Surveying

Elevations of designated measuring points were determined by completing a survey using an automatic level. Elevations were tied into the U.S. Geological Survey datum located southwest of the Colorado Tailings. Transect loops were completed to tie in elevations of all monitoring wells in the study area. All loops were closed to within 0.02 feet. Table 3-3 lists measuring point elevations of monitoring wells determined through survey.

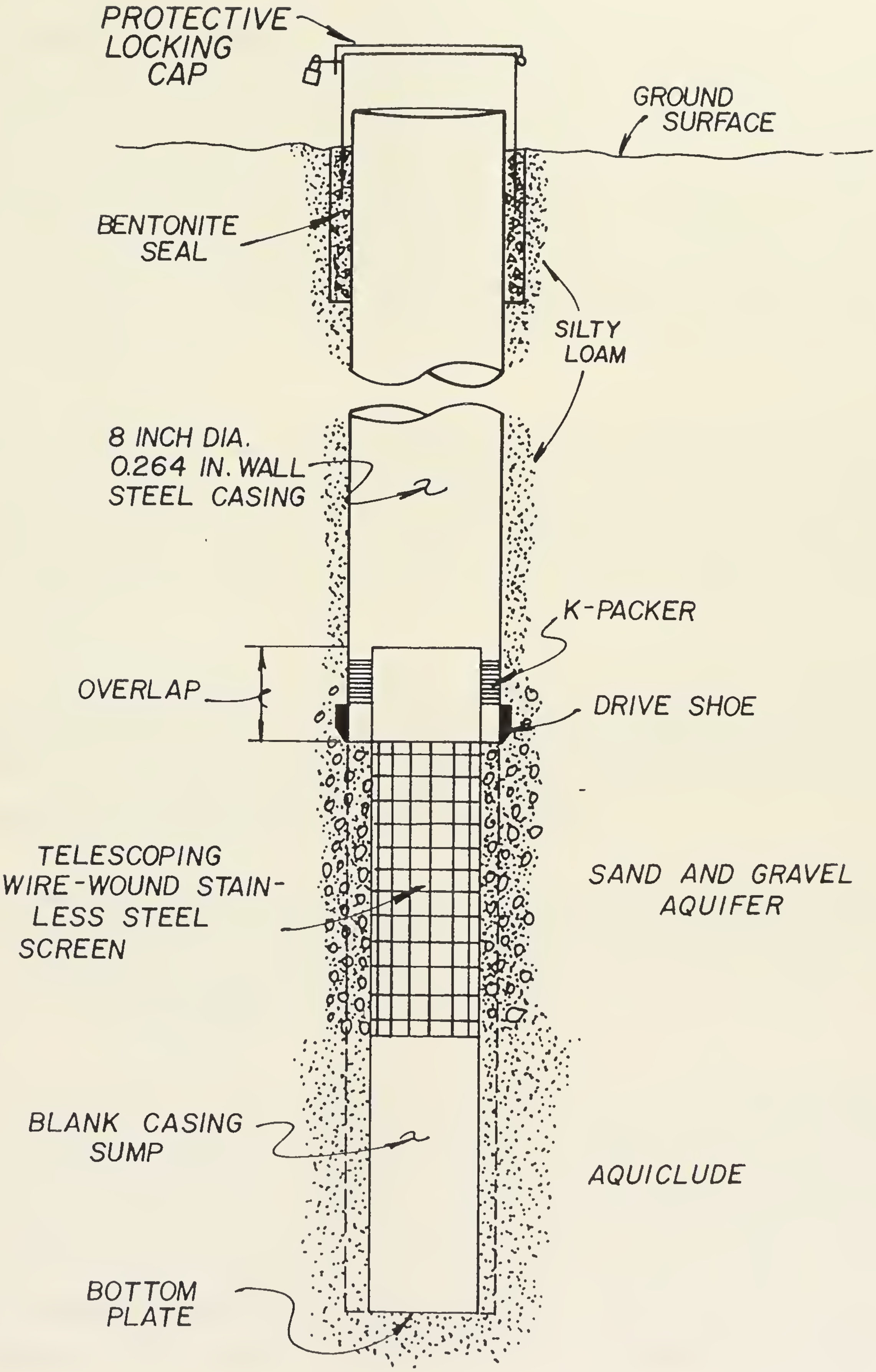
Locations of monitoring wells were field plotted on a 1 inch = 200 feet scale aerial photo base map. Spatial locations of monitoring wells were not determined by survey.

3.1.6 Aquifer Testing

Two types of aquifer tests were completed during the Phase II Remedial Investigation. These included slug tests and pumping tests. Slug tests were completed in several monitoring wells installed during the Phase I and Phase II Remedial Investigation. Pumping tests were performed at four locations within the study area in specially designed wells. Ambient conditions at each well site were recorded prior to completing the tests.

The slug tests involved insertion of a cylindrical apparatus of known dimensions into the saturated zone of each well. A pressure transducer installed in the well prior to insertion of the cylinder provided a means of measuring aquifer response to the sudden rise in water level. Water level changes induced by the introduction of the cylinder were recorded in three-second intervals by a data recorder coupled to the pressure transducer. Resultant data were downloaded into a computerized data base. Once the aquifer had stabilized to pre-test conditions, the cylinder was removed from the well and aquifer response was again measured. This procedure provided a means with which "slug-in" data could be compared to "slug-out" data.

Pumping wells were installed at four locations in the Area I Operable Unit (Exhibit I). These wells were constructed utilizing stainless steel screens containing a slot size conducive to the diameter of granular material adjacent to the targeted water-bearing unit. The wells were designed to fully penetrate the uppermost water-bearing unit and provide for maximum well efficiency. Figure 3-3 is a schematic of a typical pumping well installed during the Phase II Remedial Investigation.



Schematic of Typical Pumping Well Construction;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-3

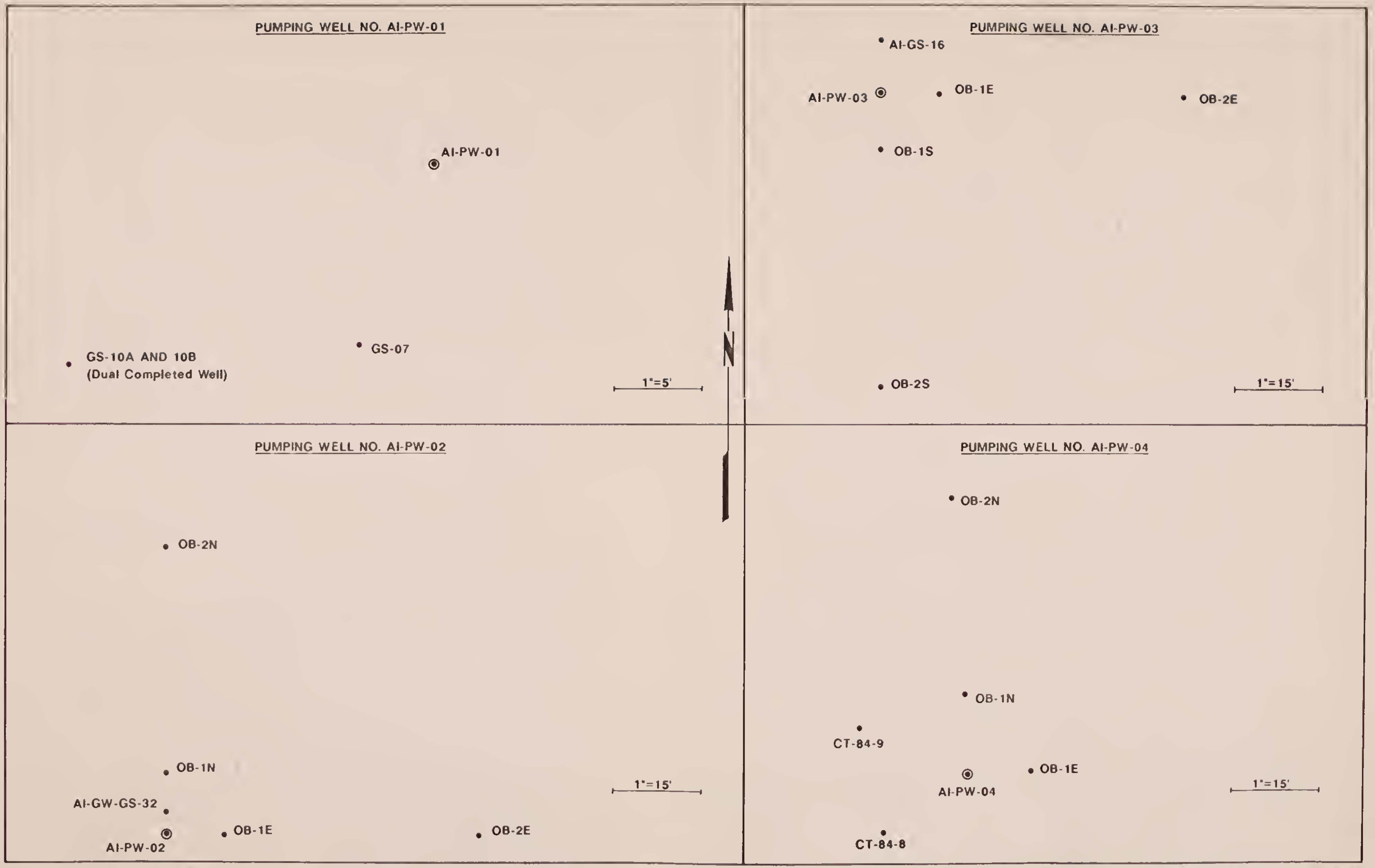
Observation wells were installed at various distances and directions from each pumping well. These wells were constructed with 2-inch diameter PVC casing emplaced at a depth of approximately 15 feet below ground surface and perforated throughout the lower five feet of the casing column. Selected monitoring wells located proximal to each pumping well were also used as observation wells during the pumping tests. Some of the monitoring wells observed during the pumping tests were completed in deeper water-bearing zones; this type of data was desired to evaluate the response of deeper aquifers to pumping of the shallow groundwater system. Figure 3-4 shows the location of observation wells with respect to each of the pumping well sites.

Pumping tests were performed by first completing a step-drawdown test at each pumping well to obtain information related to well efficiency. This procedure also allowed for determining the rate at which each well could be pumped over a long period of time. A long term pumping test commenced when water levels in the pumping well recovered to ambient conditions.

Aquifer response to pumping was monitored in the pumping well and at all observation wells utilizing pressure transducers and electric well probes. More frequent water level measurements were made during the early portion of each test; the frequency of measurements decreased as each pumping test progressed.

Pumping tests were typically run for 24 hours. Certain tests were terminated early because the groundwater system had reached relative equilibrium with the pumping rate. The purpose of the longer duration tests was to determine if localized recharge or barrier boundaries could be identified.

Following termination of each pumping test, recovery tests were completed. These tests involved monitoring water level recovery in both the pumping well and the observations wells after the pump had been turned off. Frequent measurement of water levels in the wells were made at the start of the recovery test; less frequent measurements of water levels were made with time. Collected data were recorded on field forms and on data storage modules associated with the pressure transducer systems. The recovery test was terminated when water levels had recovered to within 5% of the pre-pumping test water level.



Plan Showing Orientation of Observation Wells to Pumping Wells;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-4

Following completion of the pumping and recovery tests, data contained on data storage modules were downloaded into a computer. The pump trailer and all associated downhole equipment were decontaminated before leaving each site.

3.2 CHANGES TO THE PROJECT SAMPLING AND ANALYSIS PLAN

This section describes changes to the project work plan (CH2M HILL, 1989c) and to the project sampling and analysis plan (CH2M HILL, 1989d) which resulted from actual performance of field activities related to groundwater investigations in Area I. Rationale as to why the changes occurred is also provided.

3.2.1 Surface Geophysical Investigation

The project sampling and analysis plan (CH2M HILL, 1989d) indicated that plate reflection geophysical methods would be used to meet objectives associated with this task. Following consultation with manufacturers of surface geophysical instrumentation, it was determined that plate reflection methods were not suitable for use in Area I because of the preponderance of underground utilities in the Butte area and because the degree of definition of individual strata in unconsolidated sediment provided by plate reflection was not adequate to meet task objectives.

Plate reflection does not work well in distinguishing subtle changes in lithologic density, particularly in the upper 50 feet of unconsolidated sediments. Because it was desirable to determine the extent and thickness of suspected shallow placer deposits in the Metro Storm Drain area, it was decided that plate reflection methods were inappropriate for this application. In addition, the physical space required to complete a plate reflection line was not available in many areas within the Area I Operable Unit.

Because of the foregoing, it was decided that surface resistivity was a more appropriate surface geophysical method to meet task objectives. The surface resistivity methods offered advantages in that the system was portable and provided for relatively accurate determinations of depth to water, depth to bedrock, and provided a means of evaluating differences in electrical properties of the unconsolidated sediments associated with the site. The method was also useful in identifying trends in the specific conductivity of the shallow

groundwater system spatially. These features of the surface resistivity method presented the best opportunity to collect data to address task objectives.

Resistivity soundings were generally completed at locations described in the project sampling and analysis plan (CH2M HILL, 1989d). In certain areas, the presence of structures, underground utilities, and paved roads precluded collection of surface geophysical data. However, sufficient data were collected at accessible sites to meet task objectives.

3.2.2 Monitoring Well Installation

The project sampling and analysis plan (CH2M HILL, 1989d) indicated that monitoring wells would be installed at 28 sites in Area I. It also indicated that paired wells would be installed at 17 of the 28 sites to provide data on changes in groundwater characteristics vertically. The plan also identified probable locations for these monitoring wells.

Monitoring wells were installed at 28 sites in the Area I Operable Unit; however, well pairs were installed at only 14 of the sites. The discrepancy of three wells was the result of decisions made to not install two planned wells in the Colorado Tailings. During the time period when Phase II Remedial Investigation monitoring wells were being installed (summer, 1989), ARCO contractors installed several wells in and adjacent to the Colorado Tailings. It was decided to utilize those wells as monitoring points at this location rather than install additional monitoring wells in the same area.

Actual locations of monitoring wells installed during this investigation varied slightly from those presented in the project sampling and analysis plan (CH2M HILL, 1989d). Additional well locations were sited just south of Centennial Drive (AI-GW-GS-40), in a residential area along Grand Avenue (AI-GW-GS-46), southwest of Harrison Avenue (Well AI-GW-GS-35), southeast and upgradient of the Colorado Tailings (AI-GW-GS-22), and just west of the sewage treatment plant (AI-GW-GS-25) (Exhibit I). Wells AI-GW-GS-40 and AI-GW-GS-22 were added to provide data from areas upgradient of suspected contaminant sources. The other wells were located at sites which would bracket suspected poor quality groundwater based upon surface resistivity data and field parameter data collected during drilling activities associated with installation of the first few wells.

Monitoring wells were not installed at several locations presented in the project sampling and analysis plan. These included sites southwest of Blacktail Creek, north of the Butte Reduction Works tailings impoundment, west of the Colorado Tailings, and those sites within the Colorado Tailings described previously. Wells were not installed at these locations because surface resistivity data did not indicate a need for such wells and/or nearby wells installed by other investigators in the area were determined to be suitable for characterizing the groundwater system at these locations.

Monitoring wells installed during the Phase II Remedial Investigation in Area I were generally completed in accordance with the project sampling and analysis plan. The only exception to the proposed well design described in the sampling and analysis plan was well AI-GW-GS-50 (Exhibit I). Approximately 160 feet of steel casing was left in the borehole from 160 feet to the surface. Because the annular space between the bottom of the steel casing (160 feet below ground surface) and the top of the screened interval in the well (245 feet below ground surface) is filled with a bentonite slurry, it is improbable that the steel casing left in the borehole will affect groundwater chemistry in the monitored zone of the well.

3.2.3 Groundwater Sampling

The project sampling and analysis plan (CH2M HILL, 1989d) indicated that all monitoring wells installed during the Phase II Remedial Investigation and approximately 12 existing monitoring wells would be sampled during July, October, and April. The first sampling episode was completed in August instead of July because monitoring well installation and development work tasks were not completed until the end of July. The August sampling event did, however, coincide with the time period during which ARCO Coal Company contractors sampled AMC wells in the Butte area. In addition, available water level data indicated minimal change in groundwater elevation in Area I between July and August, 1989.

The second sampling episode was completed during November instead of October in order to coordinate the Phase II sampling event with groundwater sampling events completed by ARCO Coal Company contractors and the Montana Bureau of Mines and Geology.

A limited groundwater sampling episode in Area I is planned for April, 1990 to document temporal changes in groundwater quality within the operable unit. A separate addendum to this report will be prepared to present and summarize data resulting from the April, 1990 groundwater sampling event.

Wells sampled during the August, 1989 sampling event included those wells installed during the Phase II Remedial Investigation and 14 additional wells. The additional two wells sampled represented recently installed domestic wells discovered within and adjacent to the operable unit. The locations of the domestic wells were such that analyses of samples collected from the wells were useful in determining the nature and extent of metals contamination at the operable unit. The other twelve "additional" wells sampled during the August sampling event included all monitoring wells installed during the Phase I Remedial Investigation and one AMC monitoring well located in Clarks Park.

A total of 70 wells were sampled during the November, 1989 sampling event. Sampled wells included 42 monitoring wells installed during the Phase II Remedial Investigation and 11 monitoring wells installed during the Phase I Remedial Investigation. The other 17 wells sampled during the November event included four AMC monitoring wells located proximal to the Metro Storm Sewer, five monitoring wells installed during the summer of 1989 by ARCO Coal Company contractors, four monitoring wells installed by the Montana Bureau of Mines and Geology, three domestic wells, and pumping well AI-PW-04 located near the center of the Colorado Tailings.

A more extensive sampling effort was completed during the November, 1989 sampling episode as compared to the August sampling event to fill data gaps identified through review of August, 1989 analytical data and because synchronous groundwater quality data were not collected during November by either ARCO Coal Company or the Montana Bureau of Mines and Geology.

No other changes to the sampling plan resulted from completion of the August and November, 1989 sampling event.

3.2.4 Water Level Monitoring

No changes to the project sampling and analysis plan (CH2M HILL, 1989d) resulted in completing the groundwater monitoring task for the Area I Operable Unit Phase II Remedial Investigation.

3.2.5 Surveying

No changes to the project sampling and analysis plan (CH2M HILL, 1989d) resulted in completing the survey work task associated with the Area I Operable Unit Phase II Remedial Investigation.

3.2.6 Aquifer Testing

Only minor changes to the project sampling and analysis plan (CH2M HILL, 1989d) resulted from completion of the aquifer testing work task. The projected duration of the pumping tests presented in the sampling and analysis plan (24 hours) was not achieved in two of the four tests. Actual duration of the constant drawdown tests at wells AI-PW-01 and AI-PW-04 (Exhibit I) were 15.5 hours and 16.5 hours, respectively. The pumping test at well AI-PW-01 was terminated earlier than planned because the generator supporting the pumping apparatus failed. The pumping test at well AI-PW-04 was terminated at 16.5 hours into the test because the discharge rate began to vary. Discharge fluctuations measured during the latter part of this test complicated interpretation of collected data; a field decision was made to terminate the test early rather than collect data which may have been unusable.

No other changes to the project sampling and analysis plan resulted from completion of the aquifer testing work task.

3.3 PRESENTATION OF DATA/RESULTS

This section presents and summarizes preliminary data collected during the groundwater investigation associated with the Area I Operable Unit Phase II Remedial Investigation. Detailed analyses of these data are not included in this report; these types of analyses will be completed, as necessary, during future studies of the Area I Operable Unit and in support of site public health and environmental assessments.

3.3.1 Surface Geophysical Investigation

Figure 3-1 shows locations and orientations of resistivity soundings completed in Area I during the Phase II Remedial Investigation. Field data resulting from the resistivity survey is contained in Appendix B-1. Appendix B-1 also contains plots of apparent resistivity versus "A" spacings utilized in the soundings for each station evaluated.

Objectives of the resistivity survey completed in Area I were to:

- Identify the lateral and vertical extent of suspected placer deposits along the historic Silver Bow Creek channel.
- Determine the depth to bedrock throughout the operable unit.
- Identify areas of poor quality groundwater.
- Identify vertical and lateral changes in site lithology to provide a basis for siting monitoring wells.

Determinations of the locations and thicknesses of suspected placer deposits along the historic Silver Bow Creek channel utilizing the surface resistivity method were based on the assumption that placer deposits are characteristically well sorted coarse-grained deposits. If unsaturated, these well sorted coarse-grained zones would exhibit high electrical resistivity values due to greater void space within the placer deposits relative to the poorly sorted, fine-grained material which is characteristic of native material. If the placer deposits were saturated with relatively poor quality groundwater, it is assumed the electrical resistivity of the saturated material would be lower than the subjacent and adjacent saturated fine-grained native material.

Following completion of several resistivity soundings in areas of known degraded groundwater quality adjacent to Silver Bow Creek, it was determined that precise definition of the extent of the suspected placer deposits in Area I would be difficult with the resistivity method owing to changes in electrical resistance caused by the water table. Because the water table along the Silver Bow Creek channel is at nearly the same depth as the suspected vertical extent of historic placer deposits, changes in apparent electrical resistivity are

predominated by the conductive nature of the water table. Therefore, the presence/absence of placer deposits along the historic Silver Bow Creek channel were not readily determined during the resistivity survey.

Drilling activities associated with monitoring well installation during the Phase II Remedial Investigation did not identify any areas throughout the operable unit which could be definitively characterized as placer deposits. Therefore, based on monitoring well lithologic logs and surface resistivity data, it does not appear extensive placer deposits are present within the operable unit.

The surface resistivity technique was moderately successful in determining depth to bedrock within the operable unit. An assumption used in evaluating resistivity data derived through use of the Wenner array is that the effective depth of current induction of the resistivity instrument is approximately equal to the "A" spacing of a given sounding. Assuming that the bedrock has a higher resistivity than the overlying unconsolidated material, an increase in the apparent resistivity would occur when the "A" spacing is approximately equal to the depth to bedrock. This simplified technique proved reliable within the operable unit in areas where bedrock is relatively shallow and where buried utilities were absent.

Figure 3-5 is a map showing apparent resistivities of the upper water bearing unit and depth to bedrock based on analysis of apparent resistivity data. Examination of Figure 3-5 indicates depth to bedrock in the vicinity of the upper Metro Storm Drain area ranges from approximately 60 feet below ground surface, north of the City-County shop complex, to approximately 300 feet below ground surface near the Metro Storm Drain.

Sounding plots constructed with apparent resistivity values collected in the central Metro Storm Drain area west of Harrison Avenue indicate depth to bedrock in this area is generally greater than 200 feet below ground surface. Soundings B-16 and B-12, completed approximately 1000 feet north of the Metro Storm Drain (Figure 3-1), indicate bedrock is present at a depth of approximately 100 feet below ground surface. Weathered bedrock was encountered at this location while installing monitoring well AI-GW-GS-33 at a depth of approximately 43 feet below ground surface. The apparent discrepancy between the depth to bedrock based on the resistivity survey and the depth to bedrock based on the

Map Showing Apparent Resistivity of Upper Water Bearing Unit and Approximate Depth to Bedrock Based on Resistivity Soundings; Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-5

lithologic logs may be an indication that the upper zone of the bedrock in this area is highly weathered or mineralized.

Sounding data collected in the vicinity of the Butte Reduction Works tailing impoundments and the Colorado Tailings indicate depth to bedrock ranges from 25 to 60 feet below ground surface (Figure 3-5). The relatively shallow depth to bedrock in this area was verified during installation of several monitoring wells. Monitoring wells AI-GW-GS-12, AI-GW-GS-13A, AI-GW-GS-21D, and AI-PW-04 (Exhibit I) all encountered bedrock at depths less than 30 feet below ground surface in this area.

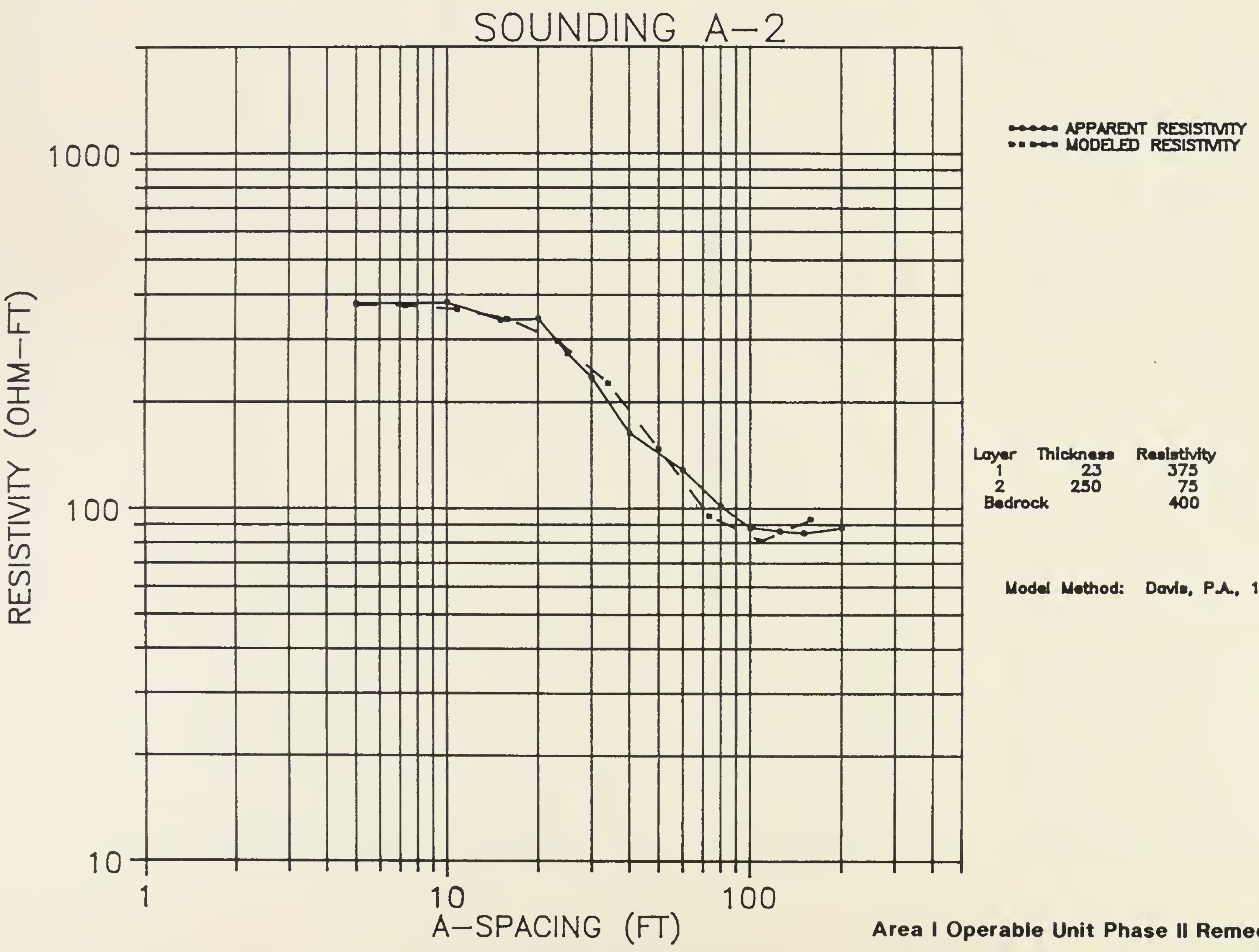
Lithologic logs for several monitoring wells installed by ARCO Coal Company contractors during the summer of 1989 indicate bedrock underlying the Butte Reduction Works area and the Colorado Tailings area is weathered to depths as great as 60 feet below ground surface. Monitoring well BMW-1B, located near the eastern edge of the Colorado Tailings (Exhibit I), encountered weathered bedrock from 36 to 60 feet below ground surface.

A more reliable method of determining depth to bedrock with surface resistivity involves matching the apparent resistivity curves presented in Appendix B-1 to theoretical sounding curves using a computer model. The modeling method provides true resistivities of each layer underlying each sounding station. A limitation of the computer modeling method is that all lithologic layers are assumed to be horizontal and laterally continuous. Several of the modeled curves provided relatively accurate estimates of the depth to bedrock within the study area.

Interpretation of resistivity data using a computer model involves inputting apparent resistivity values and their respective "A" spacings into the model and then selecting the number of suspected layers present at the site. Selection of layers for each model was based on examination of the apparent resistivity curves and lithologic logs from nearby boreholes. The computer model used for interpretation of data collected during the Phase II Remedial Investigation is an inverse model which mathematically generates theoretical curves to match the field data (Davis, 1979).

Figure 3-6 is a plot comparing apparent resistivity values measured at sounding station A-2 with a theoretical curve generated using the inverse model. Sounding A-2 was completed

Plots of Modeled vs. Apparent Resistivities Upper Metro Storm Drain Area



Layer	Thickness	Resistivity
1	23	375
2	250	75
Bedrock		400

Model Method: Davis, P.A., 1979

Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-6

in the upper Metro Storm Drain area near the City-County shop complex (Figure 3-1). Examination of Figure 3-6 indicates that two distinct layers are identifiable; bedrock is apparent at a depth of approximately 273 feet below ground surface.

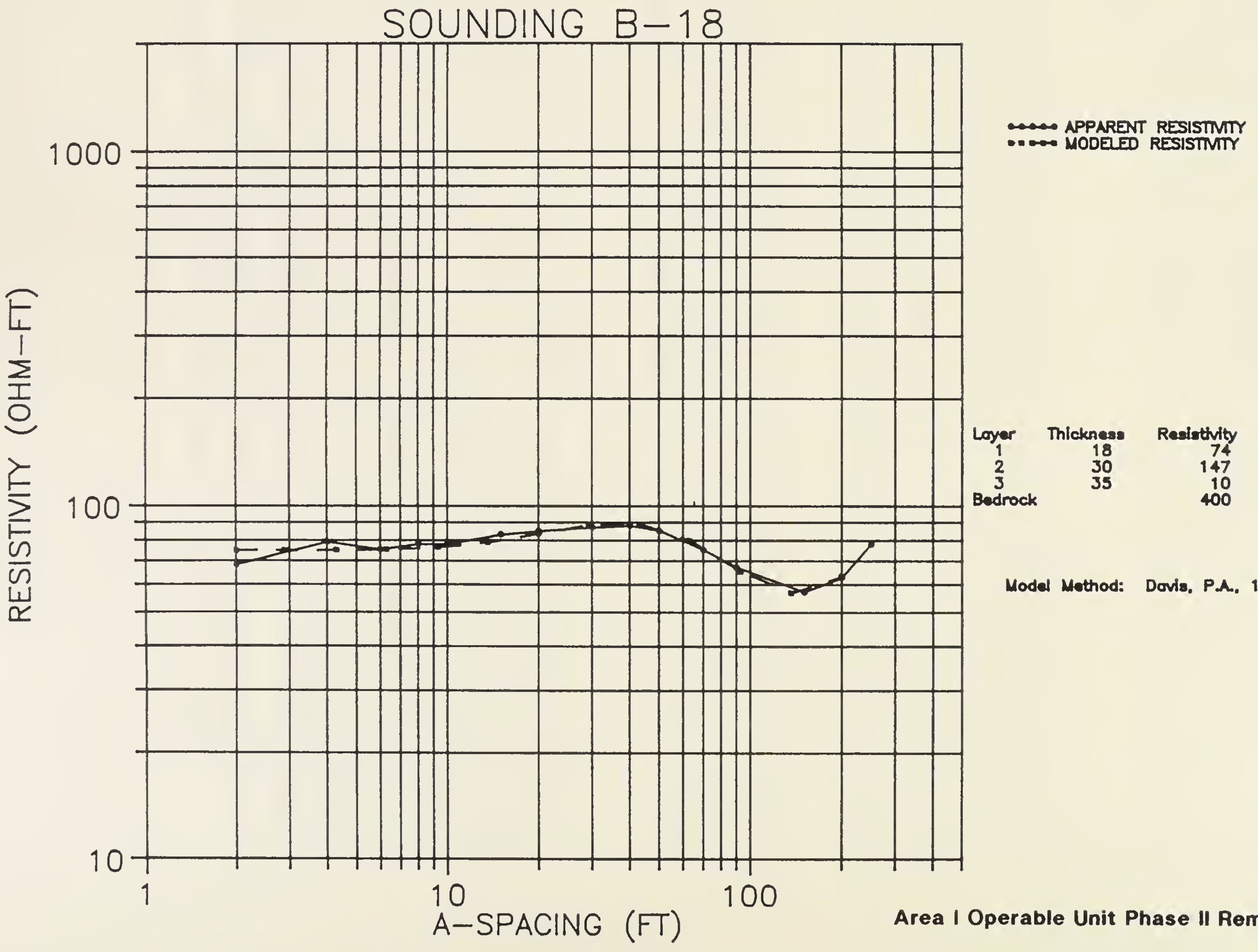
Based on the lithologic log for monitoring well AI-GW-GS-50 (Appendix B-2), completed adjacent to sounding A-2, the first layer identified on Figure 3-6 is unsaturated silty material with a thickness of approximately 23 feet. The abrupt decrease in resistivity at a depth of 23 feet below ground surface is probably attributable to the conductive nature of the water table present at this depth. The modeled curve indicates the true resistivity of the saturated unconsolidated sediments is approximately 75 ohm-feet. Bedrock was encountered while drilling monitoring well AI-GW-GS-50 at a depth of 268 feet below ground surface (Appendix B-2).

Based on data derived from resistivity sounding A-1 (Figure 3-1), depth to bedrock underlying the baseball diamonds between monitoring wells AI-GW-GS-41 and AI-GW-GS-45 (Exhibit I) is approximately 60 to 70 feet below ground surface. Although monitoring well AI-GW-GS-45 (Exhibit I) did not encounter bedrock to its total depth of 60 feet below ground surface, the clay unit encountered at the base of the borehole was similar to that identified immediately overlying the bedrock in borehole AI-GW-GS-50.

Figure 3-7 is a plot of apparent and modeled resistivity values measured at sounding station B-18 in the lower Metro Storm Drain area (Figure 3-1). The shape of the sounding curve from station B-18 is similar to the majority of sounding curves completed in the central Metro Storm Drain area. The sounding curves developed for the central Metro Storm Drain area are somewhat unique for the study area in that apparent resistivity values did not vary dramatically with an increased "A" spacing.

Based on resistivity soundings, depth to bedrock in the central Metro Storm Drain area between Harrison Avenue and Montana Street is greater than 200 feet below ground surface (Figure 3-5). Soundings B-20 and B-21 (Figure 3-1) were conducted in an area where bedrock may be shallower than 200 feet below ground surface. However, surface resistivity measurements in this area appear to have been influenced by buried electrical utilities, probably associated with a nearby transformer station.

Plots of Modeled vs. Apparent Resistivities Lower Metro Storm Drain Area



Layer	Thickness	Resistivity
1	18	74
2	30	147
3	35	10
Bedrock		400

Model Method: Davis, P.A., 1979

Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-7

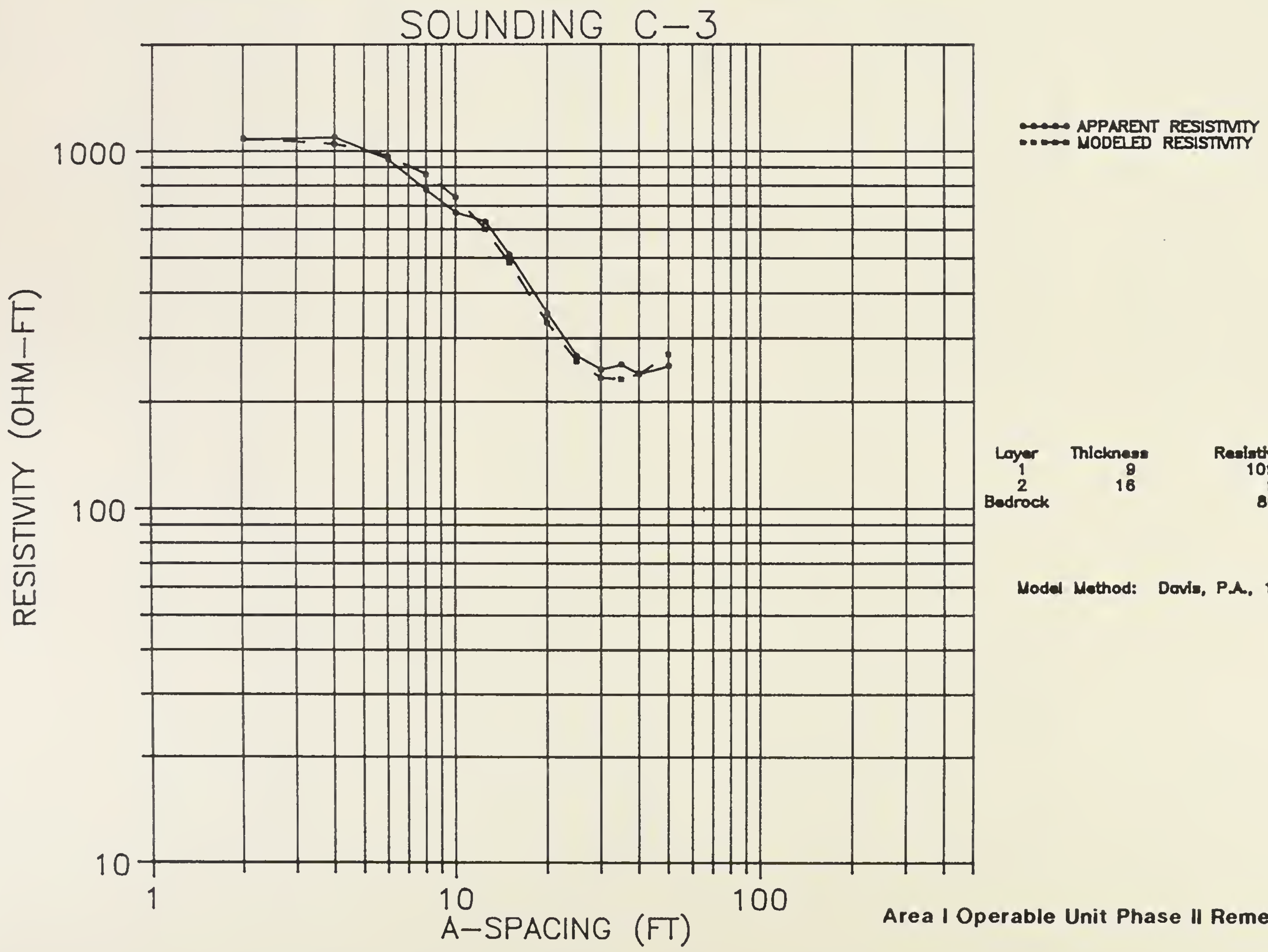
Examination of Figure 3-7 reveals the modeled curve for sounding B-18 matched the field data best when four separate layers were used. The resistivity model for sounding B-18 indicates bedrock is present at a depth of approximately 85 feet below ground surface. Monitoring well AI-GW-GS-32 (Exhibit I) was installed adjacent to sounding B-18 but was only drilled to a depth of approximately 40 feet below ground surface; bedrock was not encountered in the borehole. Monitoring well AI-GW-GS-08, located approximately 400 feet south of sounding B-18 was drilled to a total depth of 150 feet and bedrock was not encountered.

Based on the lithologic log for monitoring well AI-GW-GS-33 (Exhibit I), the upper 18 foot thick layer is likely a saturated clayey sand with a true resistivity of approximately 75 ohm-ft. The second layer, exhibiting a true resistivity of approximately 150 ohm-ft, is likely the relatively transmissive gravel zone observed to yield a comparatively large quantity of water during drilling of well AI-GW-GS-33. The abrupt drop in resistivity at a depth of approximately 50 feet below ground surface is suspected to represent a fine grained zone.

Based on resistivity data, depth to bedrock west of Montana Street in the Butte Reduction Works tailings impoundment area and the Colorado Tailings area ranges from 60 feet at sounding station C-7 to 25 feet at sounding C-1 (Figure 3-5). These depths coincide relatively well with depths to bedrock reported on borehole logs for monitoring wells completed in these areas.

Figure 3-8 is a plot of apparent resistivity values collected at sounding C-3 with its associated modeled curve. Sounding C-3 was completed in the vicinity of the Butte Reduction Works area (Figure 3-1) near monitoring well AI-GW-GS-12 (Exhibit I). Review of Figure 3-8 indicates bedrock was encountered at a depth of approximately 25 feet below ground surface. Bedrock was encountered while installing monitoring well AI-GW-GS-12 at a depth of approximately 29 feet below ground surface. Based on the lithologic log for monitoring well AI-GW-GS-12 (MultiTech, 1987), the upper nine foot layer identified with the sounding model is probably unsaturated silty sand. The abrupt decrease in resistivity at a depth of nine feet below ground surface is indicative of the water table, measured at approximately nine feet below ground surface in monitoring well AI-GW-GS-12.

Plots of Modeled vs. Apparent Resistivities Butte Reduction Works Area



Layer	Thickness	Resistivity
1	9	1090
2	16	90
Bedrock		800

Model Method: Davis, P.A., 1979

Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-8

The true resistivity of the saturated layer at sounding C-3 is approximately 90 ohm-ft, which is slightly higher than the true resistivity of the upper saturated layer measured at sounding A-2, where the presence of relatively poor quality groundwater was documented. Water quality samples collected from monitoring well AI-GW-GS-12, located adjacent to sounding C-3, indicate the specific electrical conductance of the shallow groundwater in this area is approximately 600 umhos per centimeter @ 25° C. Water quality samples collected from monitoring well AI-GW-GS-10S, located adjacent to sounding A-2 indicate the specific electrical conductance is approximately 2000 umhos per centimeter at 25 degrees centigrade.

Zones of poor quality groundwater were determined with surface resistivity data based on the assumption that poor quality groundwater associated with mine wastes exhibits relatively high specific electrical conductance. Therefore, areas of poor quality groundwater would exhibit relatively low apparent resistivity values. Examination of Figure 3-5 indicates apparent resistivities for the upper water bearing unit in the upper Metro Storm Drain area is relatively low as compared to areas north, east, and south of this area. Apparent resistivity values for the upper water bearing unit in the Butte Reduction Works area and the Colorado Tailings area (Figure 3-5) also exhibited relatively low resistivity values.

3.3.2 Monitoring Well Installation

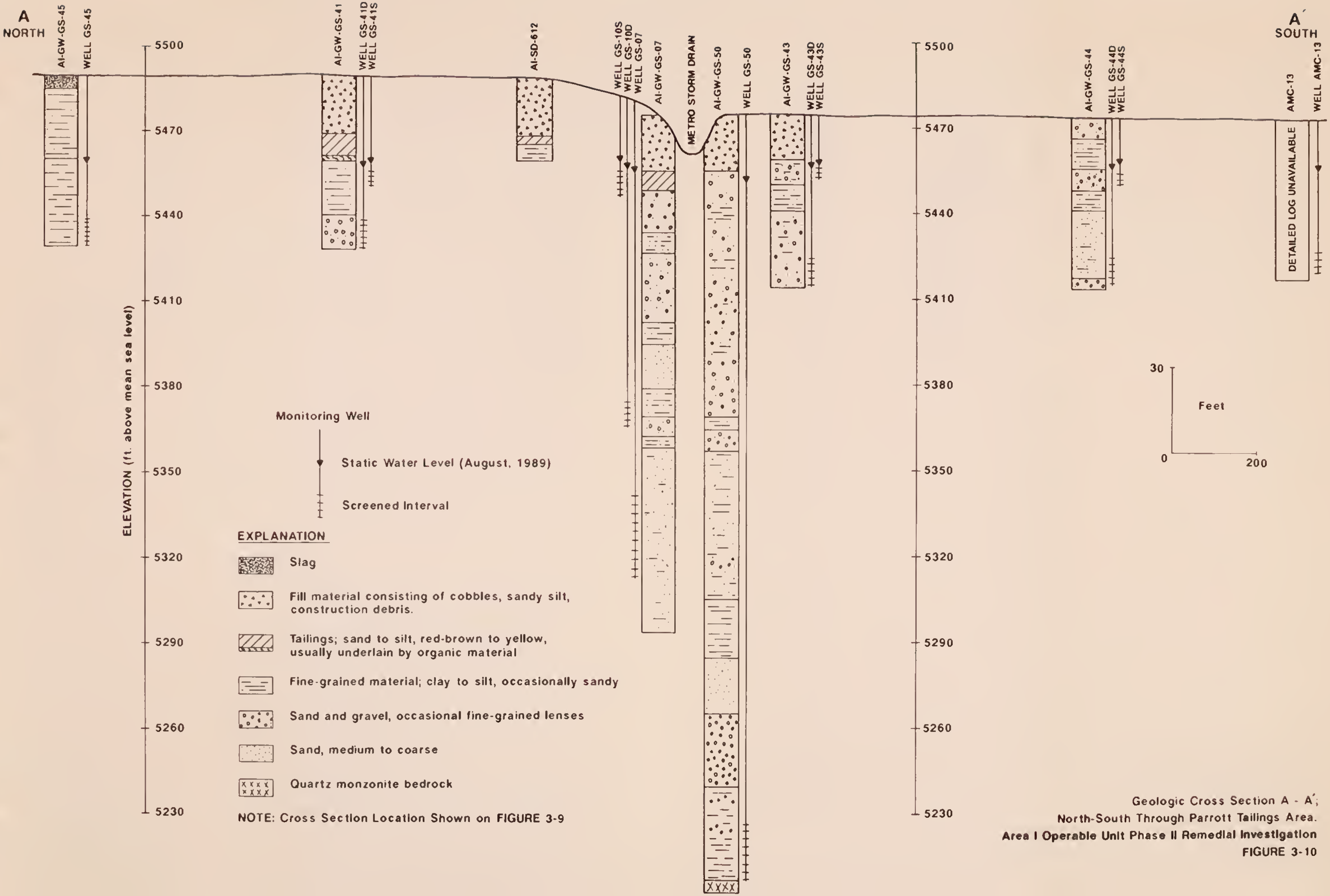
Locations of monitoring wells installed in Area I during the Phase II Remedial Investigation are shown on Exhibit I. Lithologic and well completion logs for each monitoring well are contained in Appendix B-2. Appendix B-3 is a well inventory data base for Phase I and Phase II Remedial Investigation monitoring wells and selected other wells in Area I.

3.3.2.1 Lithology

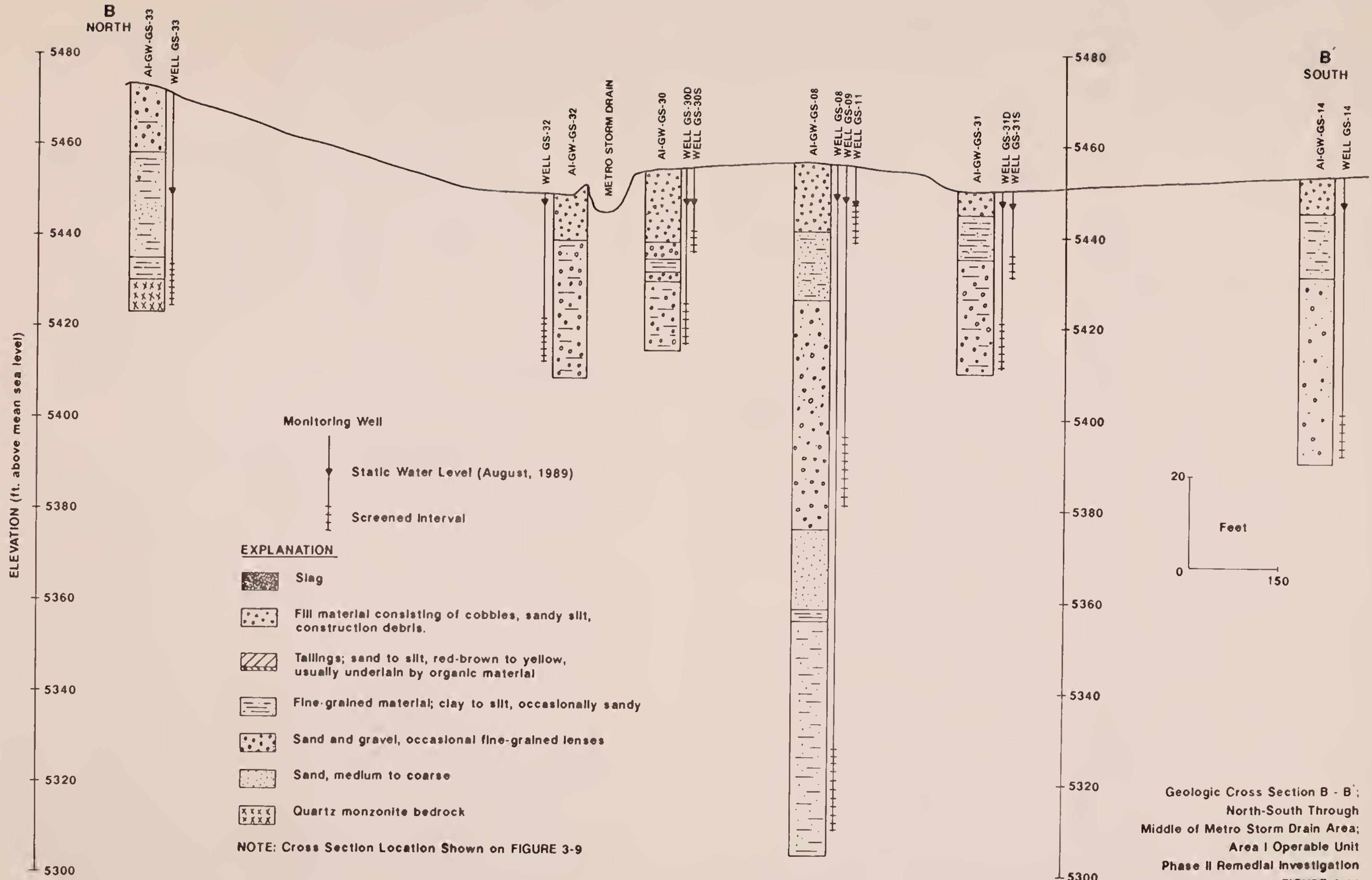
Metro Storm Drain Area

Lithologies encountered during drilling activities associated with monitoring well installation in the Area I Operable Unit generally included manganese slag, fill material, mine and mill tailings, sand and gravel, and sandy silt. Figure 3-9 shows locations of geologic cross sections described in this section of the report. Figures 3-10 and 3-11 are geologic cross sections oriented perpendicular to the Metro Storm Drain near the upper and middle

Locations of Geologic Cross Sections;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-9



Geologic Cross Section A - A′;
North-South Through Parrott Tailings Area.
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-10



Geologic Cross Section B - B′;
North-South Through
Middle of Metro Storm Drain Area;
Area I Operable Unit
Phase II Remedial Investigation
FIGURE 3-11

reaches of the drain, respectively. Figure 3-12 is a longitudinal geologic cross section oriented parallel to the Metro Storm Drain from its head to near its mouth.

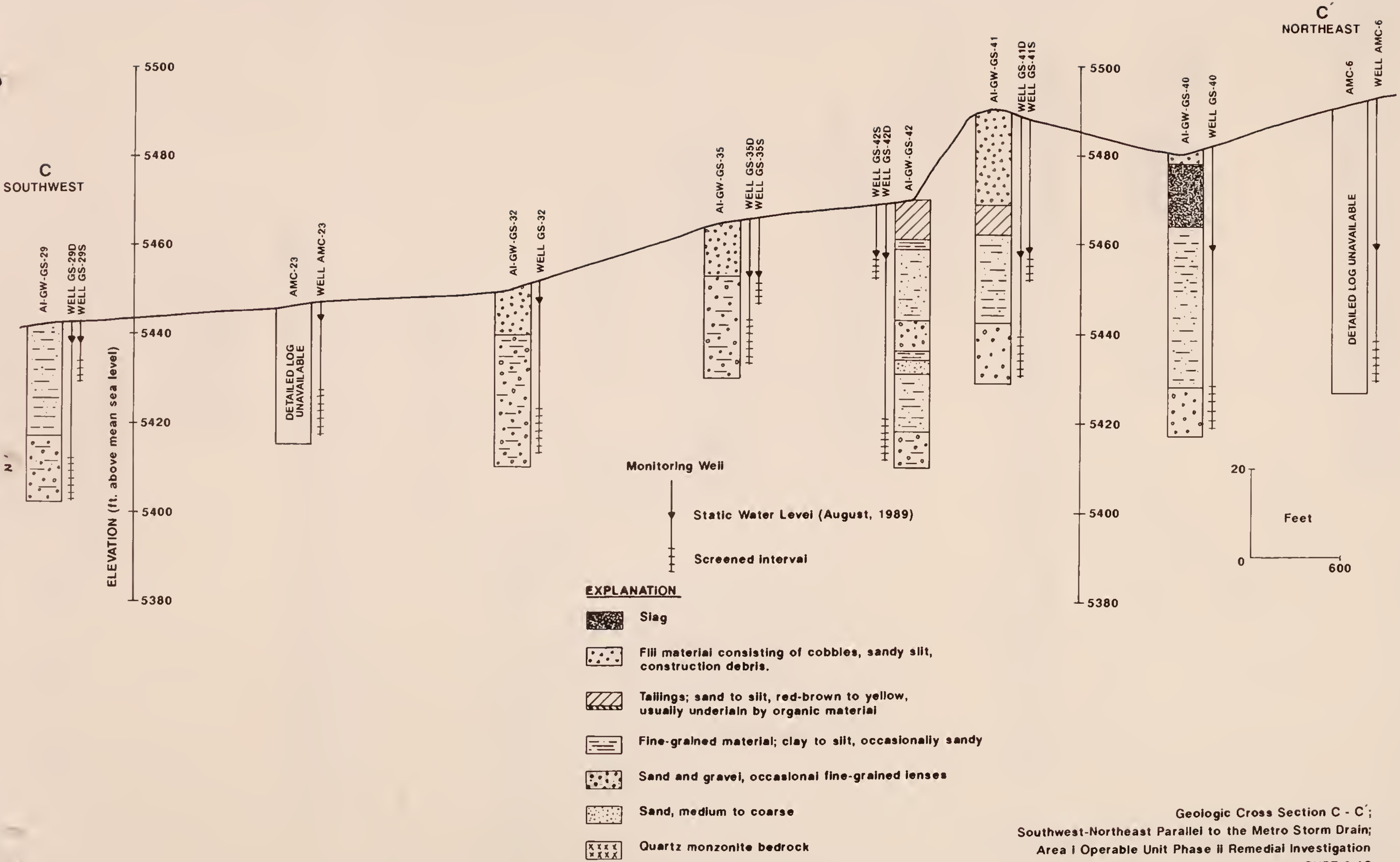
Examination of these figures indicates the near surface lithology in the vicinity of the Metro Storm Drain is characterized by fill material ranging in thickness from a few feet to over 20 feet. The fill material encountered during drilling activities was characterized by poorly sorted material consisting of cobbles, sand, silt, construction debris, and occasionally slag. This material was typically underlain by varying thicknesses of mine and mill tailings, particularly near the upper end of the Metro Storm Drain.

A relatively coarse-grained poorly sorted sand and gravel or sand unit was generally encountered beneath the tailings or fill material (Figure 3-10). This unit is typically present approximately 20 feet below ground surface and is about 80 feet thick. The relatively coarse-grained unit contains several fine-grained interbeds that are not easily correlatable between boreholes. The shallow coarse-grained unit generally yielded water at a rate ranging from five to 20 gallons per minute (gpm) during borehole advancement.

Limited information suggests the lithology beneath the shallow coarse-grained unit consists of alternating beds of silty sands and clayey silts. These units typically produced water during drilling at a rate of less than one gpm. A relatively clean gravel unit was encountered during drilling of monitoring well AI-GW-GS-50 (Exhibit I) at a depth of 210 feet below ground surface (Figure 3-10). This unit was approximately 25 feet thick and produced water in excess of 100 gpm, based upon observations made during drilling. Silty sand was present beneath this gravel unit; bedrock was encountered at well AI-GW-GS-50 at a depth of 268 feet below ground surface. The bedrock penetrated was comprised primarily of quartz monzonite.

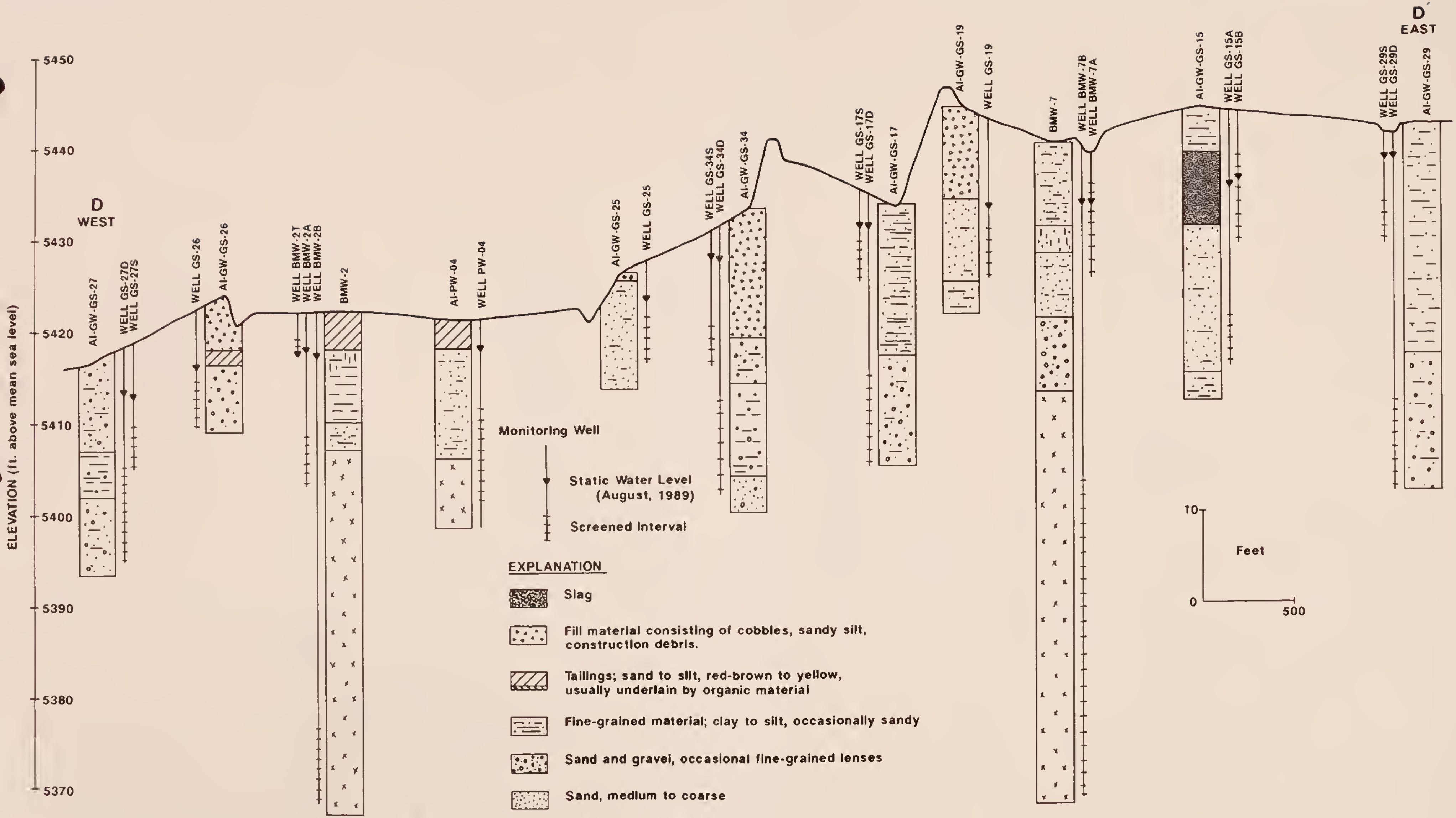
Silver Bow Creek Area

Lithologies in the area along Silver Bow Creek from near Montana Street to below the Colorado Tailings generally consist of mine and mill tailings, slag material, fill material, sand and gravel, and sandy silt. Figures 3-13 and 3-14 are geologic cross sections of the lower reaches of Area I oriented parallel and perpendicular to the valley axis, respectively.



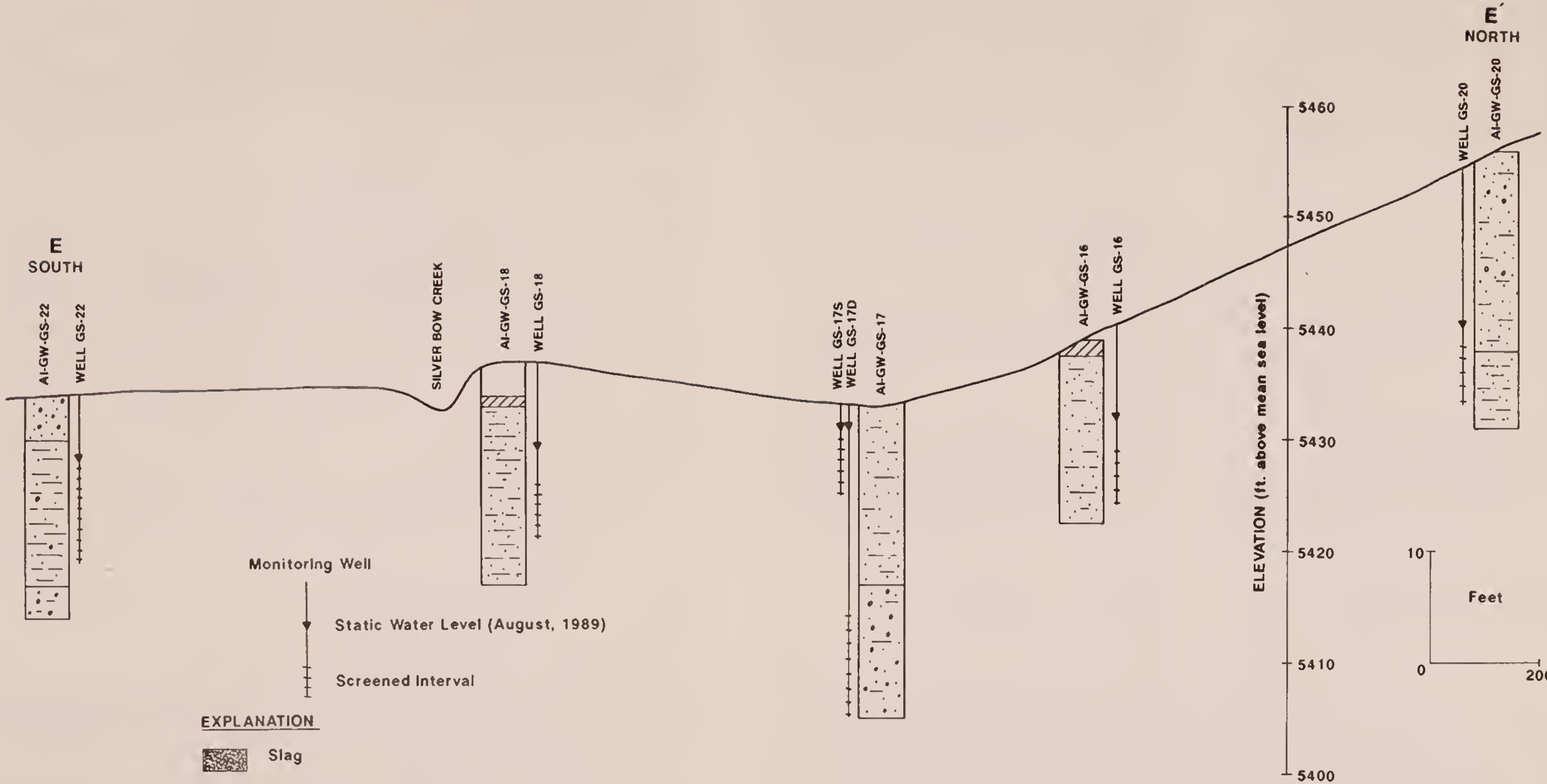
NOTE: Cross Section Location Shown on FIGURE 3-9

Geologic Cross Section C - C′;
Southwest-Northeast Parallel to the Metro Storm Drain;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-12



NOTE: Cross Section Location Shown on FIGURE 3-9

Geologic Cross Section D - D´;
West-East from West of Colorado Tailings to Montana Street;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-13



EXPLANATION

- Slag
- Fill material consisting of cobbles, sandy silt, construction debris.
- Tailings; sand to silt, red-brown to yellow, usually underlain by organic material
- Fine-grained material; clay to silt, occasionally sandy
- Sand and gravel, occasional fine-grained lenses
- Sand, medium to coarse
- Quartz monzonite bedrock

NOTE: Cross Section Location Shown on FIGURE 3-9

Geologic Cross Section E - E´;
South-North Through the Butte Reduction Works Area;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-14

Near surface lithologies in the lower half of Area I are typified by mine and mill tailings, primarily in the vicinity of the Colorado Tailings and Butte Reduction Works tailings impoundments, and by manganese slag deposits near the Butte Sewage Treatment Plant. Fill material is also present near surface at several locations in the area. Silty sand deposits generally underlie the near surface materials. A sand and gravel unit is often present beneath either the near surface materials or the silty sand deposits (Figures 3-13 and 3-14). This sand and gravel unit yielded the greatest quantities of water during drilling activities in this area (10 to 20 gpm). Bedrock was encountered at several locations in the lower half of Area I at depths ranging from approximately 25 to 35 feet below ground surface.

3.3.2.2 Monitoring Well Completions

The primary focus of groundwater investigations associated with the Phase II Remedial Investigation in Area I was on the shallow groundwater-bearing units. For this reason, many of the monitoring wells installed during the study were completed in the upper five to 10 feet of the first groundwater-bearing unit encountered during drilling. Several well pairs were also installed to provide a basis for evaluating vertical changes in water levels and in groundwater quality. The deeper completion of well pairs was either completed in the second identifiable groundwater bearing zone (when encountered) or within the first water-bearing unit at a deeper interval. In the former case, a fine-grained aquitard generally separated the screened intervals of each set of well pairs. In the latter case, field parameters monitored in water samples collected during drilling activities were evaluated to determine an appropriate completion interval for the deeper completion. When measurable changes in specific conductivity and pH were identified, the deeper well was completed in that zone.

A relatively deep (268 foot) monitoring well was installed near the City-County shop complex (AI-GW-GS-50, Exhibit I). The purpose of this monitoring well was to provide data to determine the vertical extent and source of metals contamination in groundwater in this area. This well was screened in the lower 20 feet of the unconsolidated material, just above its contact with bedrock. Material samples were collected at depth while advancing the borehole and analyzed for total metals to determine if the relatively poor quality groundwater identified at depth in this area was attributable to natural mineralization or other sources.

Completion logs for monitoring wells installed during the Phase II Remedial Investigation are contained in Appendix B-2.

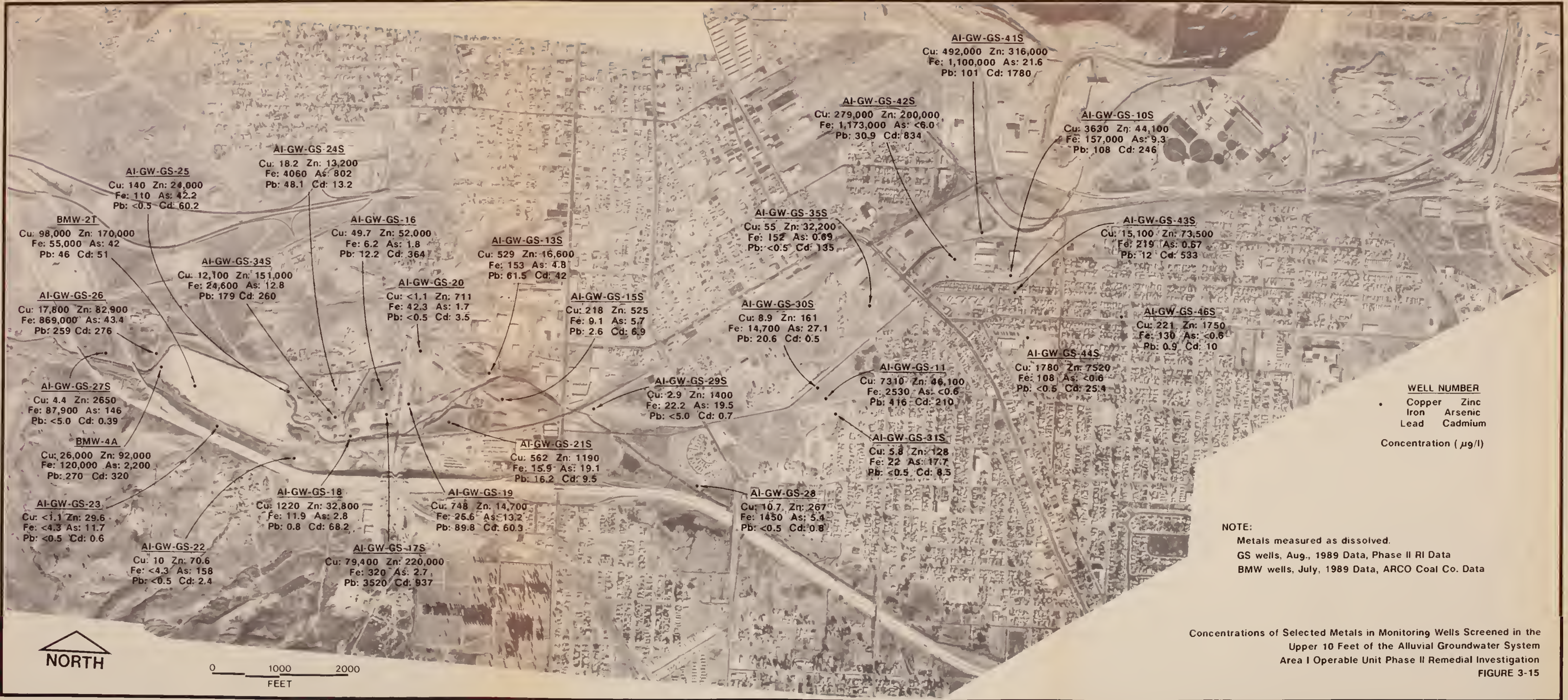
3.3.3 Groundwater Sampling

Phase II Remedial Investigation groundwater quality data resulting from sampling in Area I during August and November, 1989 are contained in Appendix B-4. Figure 3-15 summarizes concentrations of dissolved arsenic, cadmium, zinc, copper, iron, and lead spatially for wells completed in the upper 10 feet of the alluvial groundwater system. Figure 3-16 shows concentrations of these same metals spatially for wells completed between 10 and 40 feet below the water table.

Groundwater quality generally improves with depth throughout the operable unit. Figures 3-17 and 3-18 illustrate this phenomenon for selected metals at locations near the City-County shop complex and near Kaw Avenue, respectively. Most metals parameters sampled decrease to near laboratory detection limits at a depth of approximately 150 to 250 feet below ground surface near the City-County shop complex (Figure 3-17) and at a depth of less than 150 feet below ground surface in the middle reaches of the Metro Storm Drain (Figure 3-18).

Figures 3-19 and 3-20 depict vertical trends in concentrations of selected metals in groundwater beneath the southern cell of the Butte Reduction Works tailing impoundments and west end of the Colorado Tailings, respectively. Highest metals concentrations in groundwater at the Butte Reduction Works tailing impoundments occur in the upper few feet of the groundwater system (Figure 3-19). Metal concentrations decrease rapidly with depth to near laboratory detection limits within the upper 10 to 15 feet of the groundwater system at this site. These trends indicate that the source to metals contamination in the alluvial groundwater system in the vicinity of the Butte Reduction Works tailing impoundments is near surface and vertical migration of metals contaminants is minimal.

Metal concentrations in groundwater beneath the west end of the Colorado Tailings exhibit vertical trends which are unique with respect to those measured elsewhere in Area I. Dissolved copper, zinc, and cadmium appear to decrease in concentration in the upper 20 feet of the alluvial groundwater system and then increase with depth into the underlying

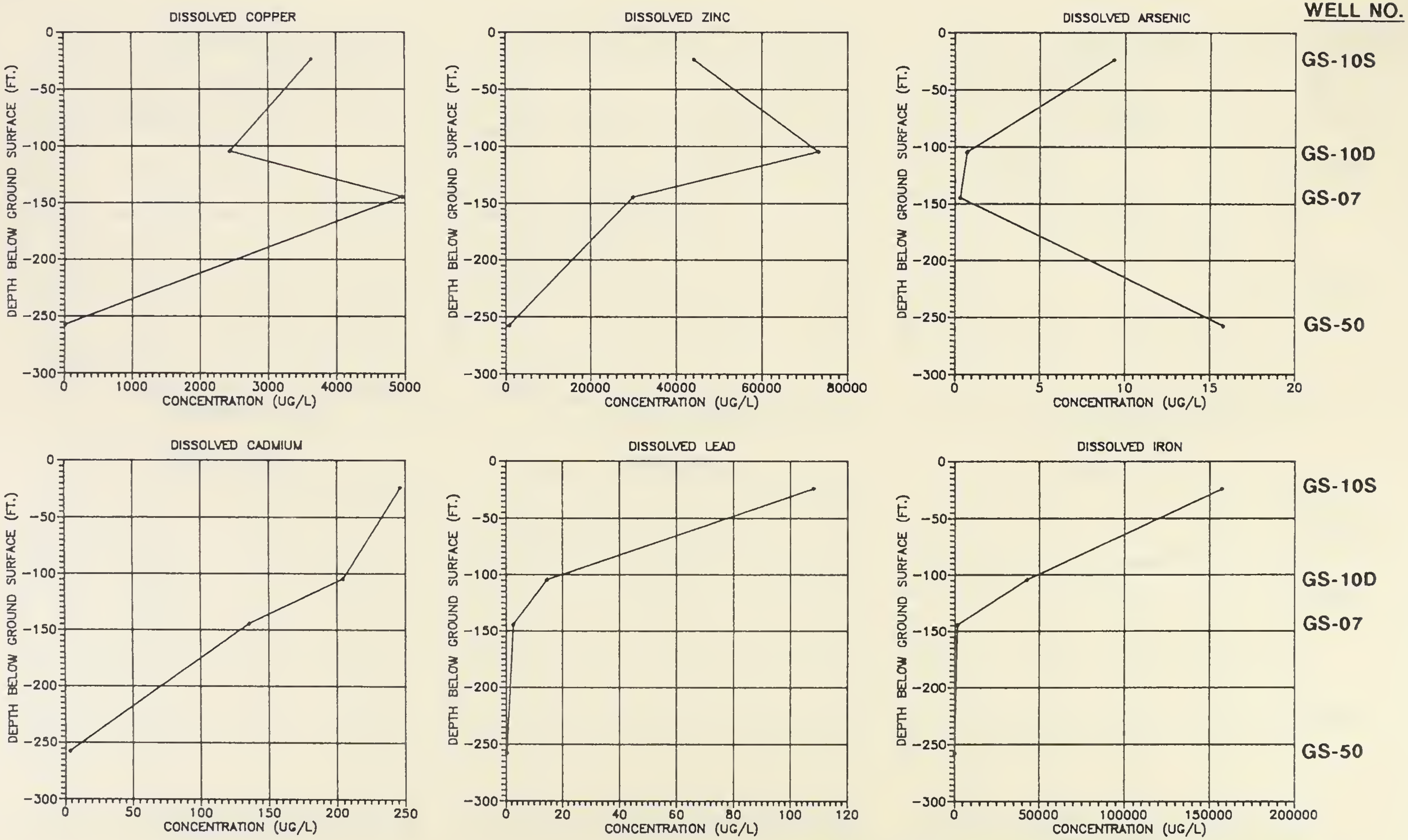


Concentrations of Selected Metals in Monitoring Wells Screened in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-15

Concentrations of Selected Metals in Monitoring Wells Screened from 10 to 40 Feet Below Water Level in the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-16

(August, 1989 Data)

Vertical Distribution of Selected Metals Concentrations near the City-County Shop Complex;

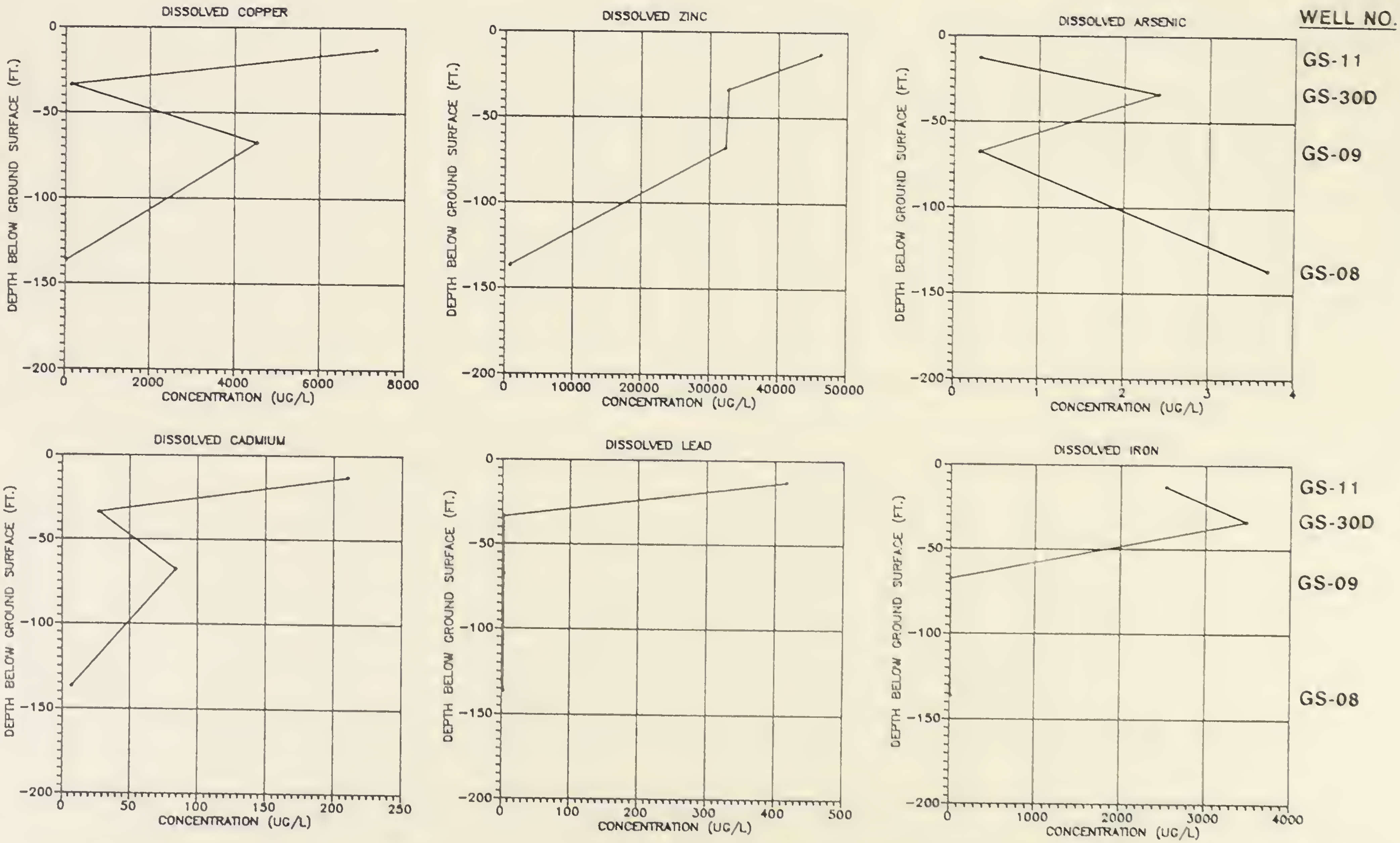


Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-17

(August, 1989 Data)

Vertical Distribution of Selected Metals Concentrations near Kaw Avenue:

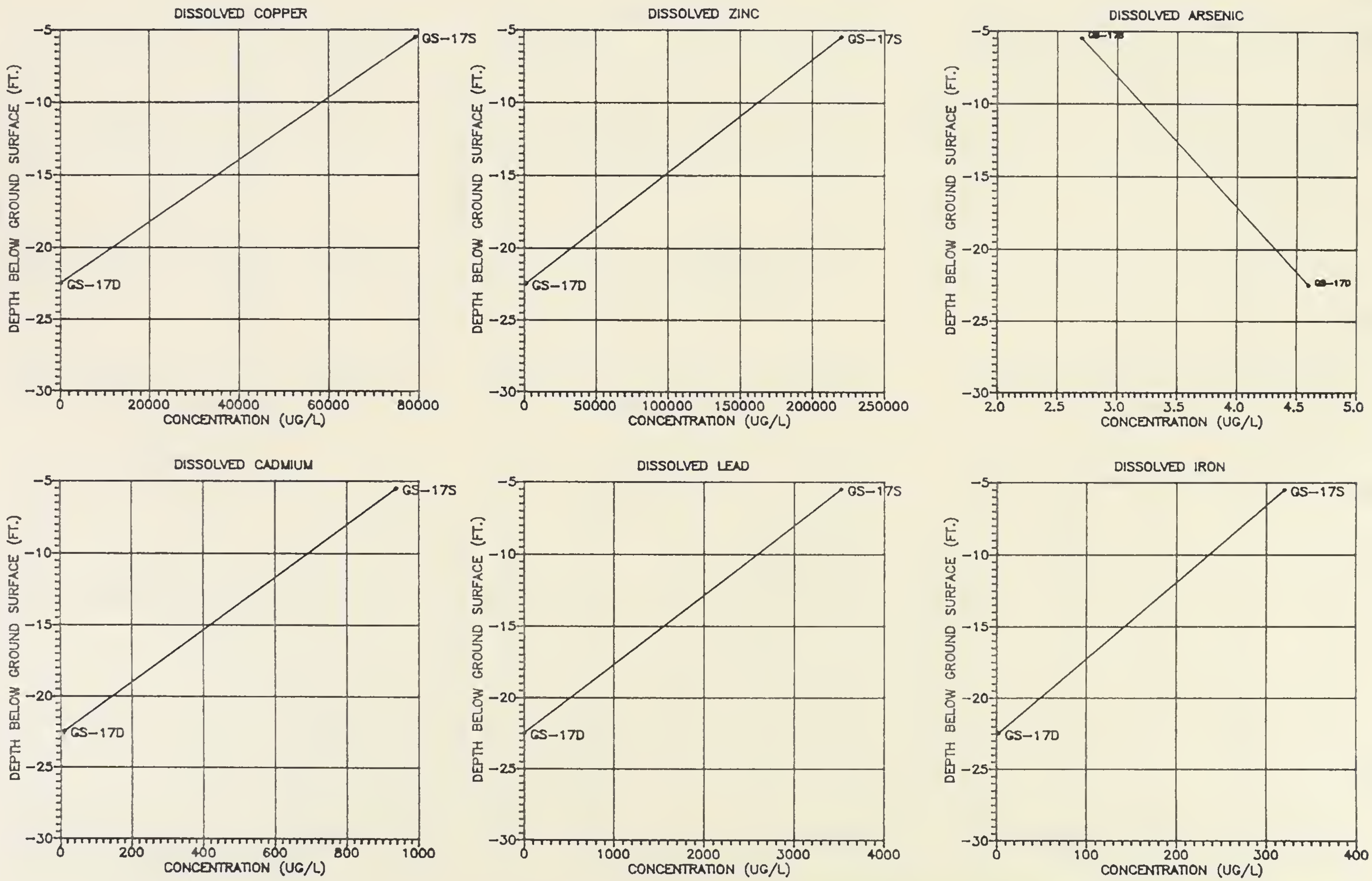


Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-18

(August, 1989 Data)

Vertical Distribution of Selected Metals Concentrations in the Butte Reduction Works Tailing Impoundments Area

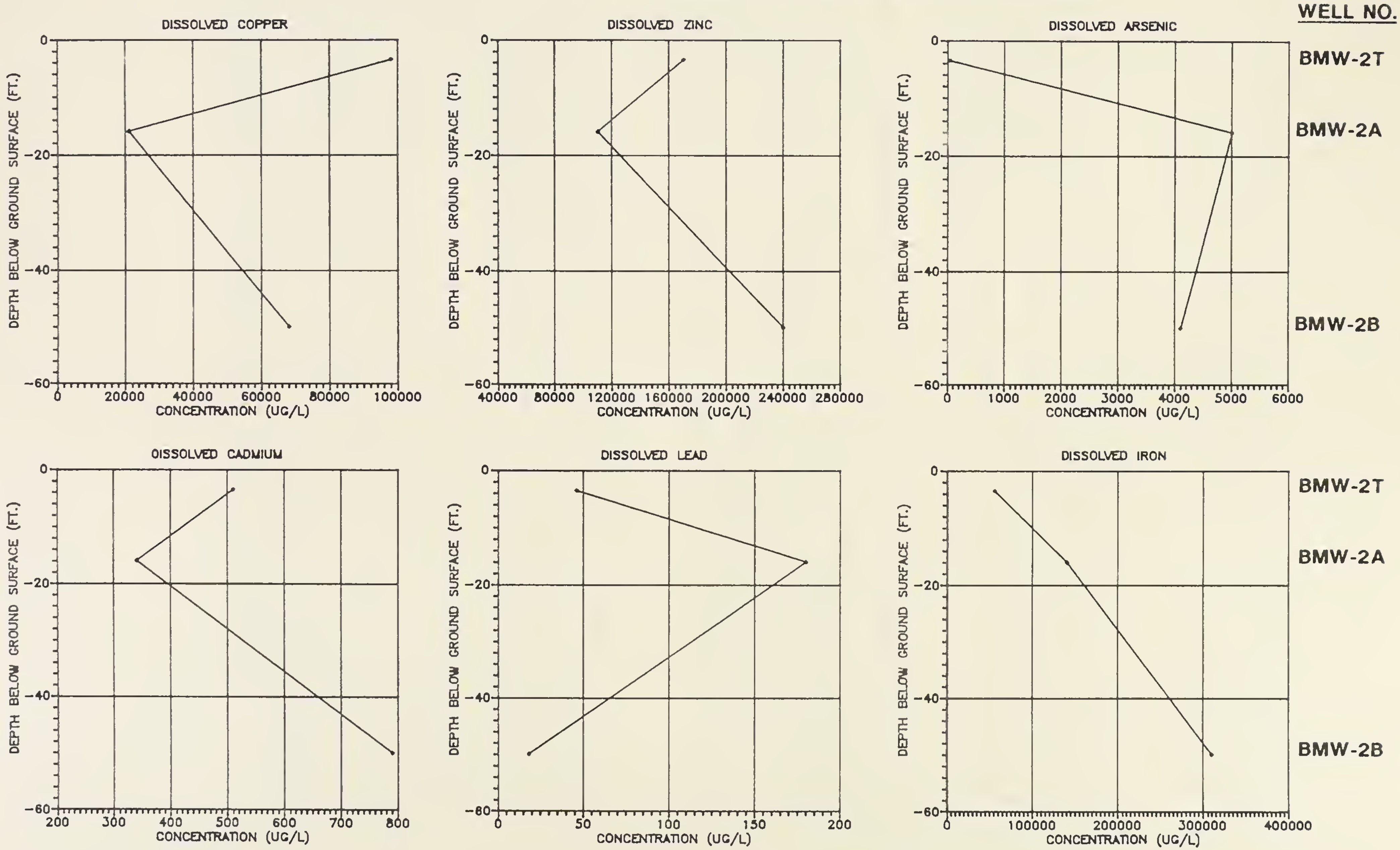


Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-19

(August, 1989 Data)

Vertical Distribution of Selected Metals Concentrations in the Colorado Tailings



Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-20

bedrock groundwater system (Figure 3-20). Dissolved lead concentrations increase with depth in the alluvial groundwater system and then decrease into the underlying bedrock system. Dissolved arsenic and iron concentrations generally increase with depth into the bedrock groundwater system (Figure 3-20).

The vertical distribution of metals in groundwater beneath the west end of the Colorado Tailings indicates the system is complex with respect to contaminant sources and pathways of contaminant movement. Based on the vertical distribution of dissolved copper, zinc, and cadmium, a near surface source of metals is present in the area. Arsenic and lead appear to accumulate near the base of the alluvial groundwater system.

The presence of relatively high metals concentrations in the bedrock system at the west end of the Colorado Tailings may indicate the hydraulics of groundwater movement in the Colorado Tailings area is affecting metals contaminant transport from shallow contaminant sources (see Section 3.3.4). Alternatively, relatively high metals concentrations in the bedrock system at this location may indicate a deeper source of metals is present. The vertical extent of metals contamination in the Colorado Tailings was not determined during this investigation.

Figures 3-21 through 3-32 are isopleths of dissolved copper, zinc, arsenic, cadmium, lead, and iron in the shallow (upper 10 feet) alluvial groundwater system and in the deeper (between 10 and 40 feet below water level) portion of the alluvial groundwater system. The majority of data presented on these figures was derived from sampling completed during a common time period in Area I. However, some data presented were obtained by other investigators of the Butte area during different time periods. It is recognized that presentation of groundwater quality data from different time periods may not accurately depict the extent and severity of metals contamination in Area I. However, these data have been included in the isopleths to provide as much information as practicable on the quality of groundwater in Area I. The same general iso-contours can be developed on the isopleth maps using only synchronous data obtained during the remedial investigation.

NOTE:

GS and BMW wells - July and August, 1989 Data, Phase II RI Data and ARCO Data

MF, MP and S wells - December, 1985 Data Phase I RI Data

AMC-8 and AMC-24 wells - July, 1988 Data, ARCO Coal Co. Data

Other wells - 1983 Data, MBMG Data

Isopleth of Dissolved Copper Concentrations
in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-21

NOTE:

GS, DW, BMW wells and AMC-13 - July and August, 1989 Data Phase II RI Data and ARCO Data

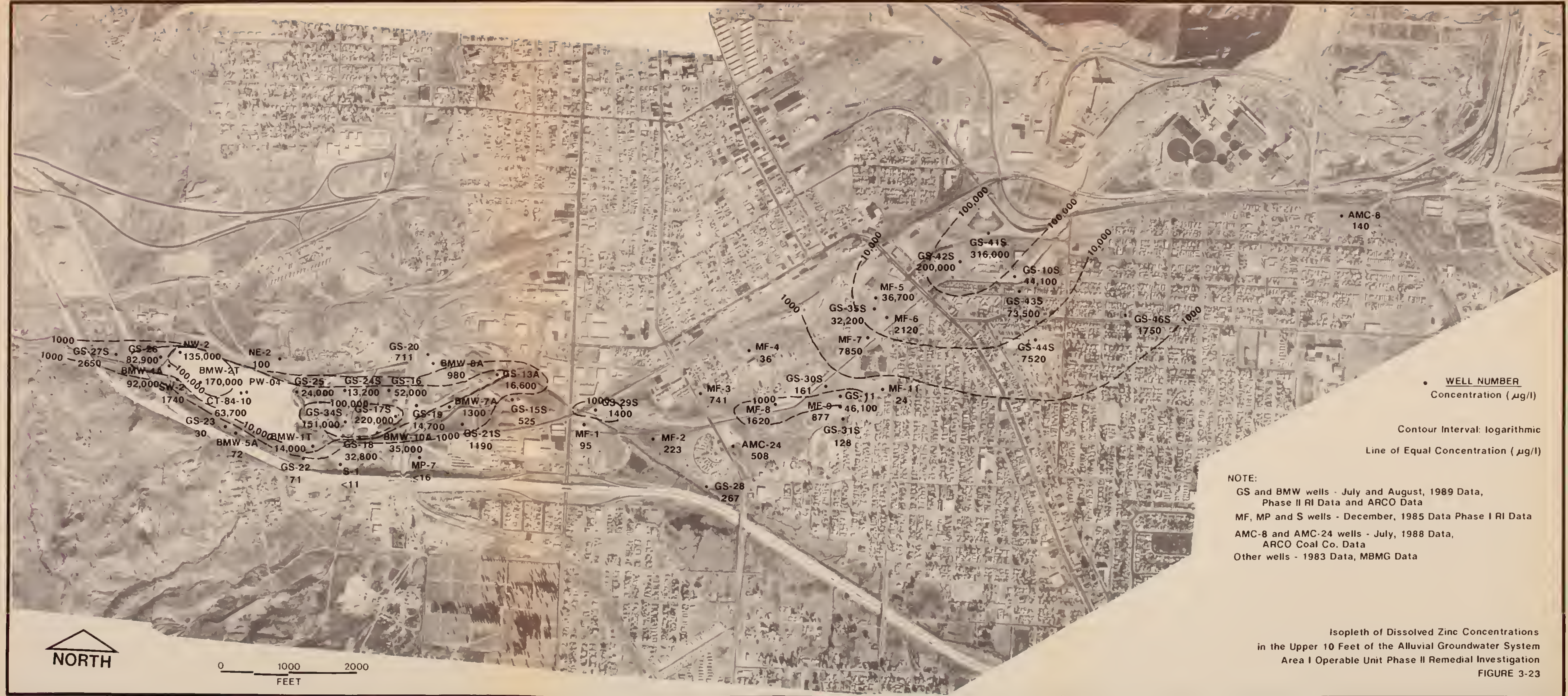
MF wells and AMC-12 - December, 1985 Data, Phase I RI Data

CT and NW wells - 1983 Data, MBMG Data

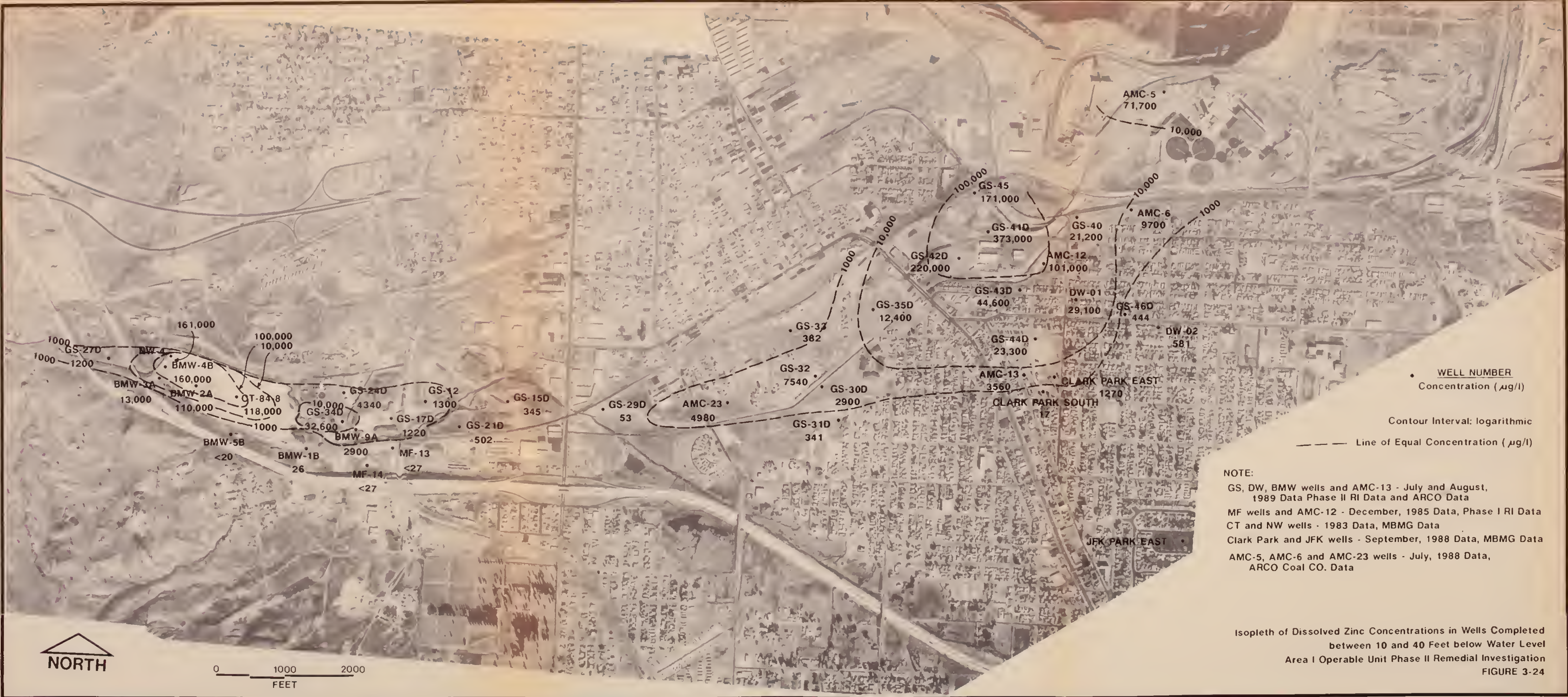
Clark Park and JFK wells - September, 1988 Data, MBMG Data

AMC-5, AMC-6 and AMC-23 wells - July, 1988 Data, ARCO Coal CO. Data

Isopleth of Dissolved Copper Concentrations in Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-22



Isopleth of Dissolved Zinc Concentrations
in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-23



NOTE:

GS, DW, BMW wells and AMC-13 - July and August, 1989 Data Phase II RI Data and ARCO Data

MF wells and AMC-12 - December, 1985 Data, Phase I RI Data

CT and NW wells - 1983 Data, MBMG Data

Clark Park and JFK wells - September, 1988 Data, MBMG Data

AMC-5, AMC-6 and AMC-23 wells - July, 1988 Data, ARCO Coal CO. Data

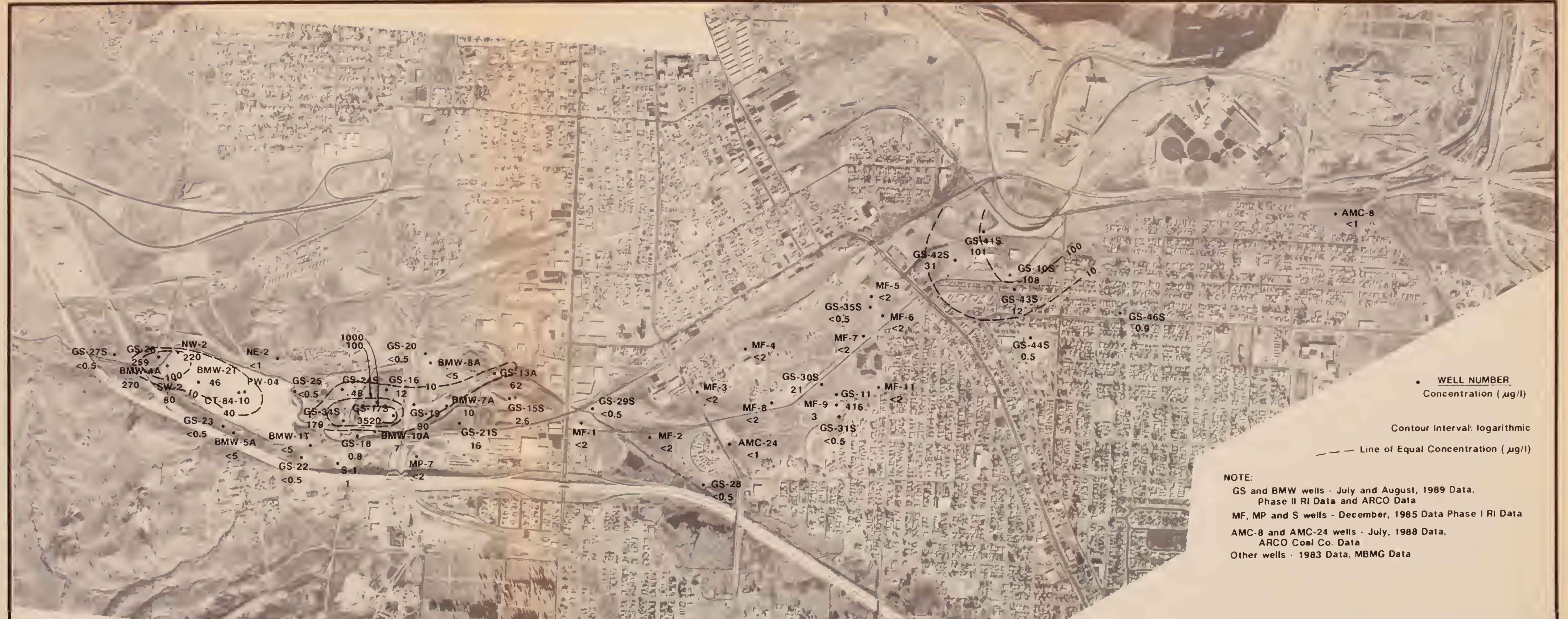
Isopleth of Dissolved Zinc Concentrations in Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-24

Isopleth of Dissolved Arsenic Concentrations
in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-25

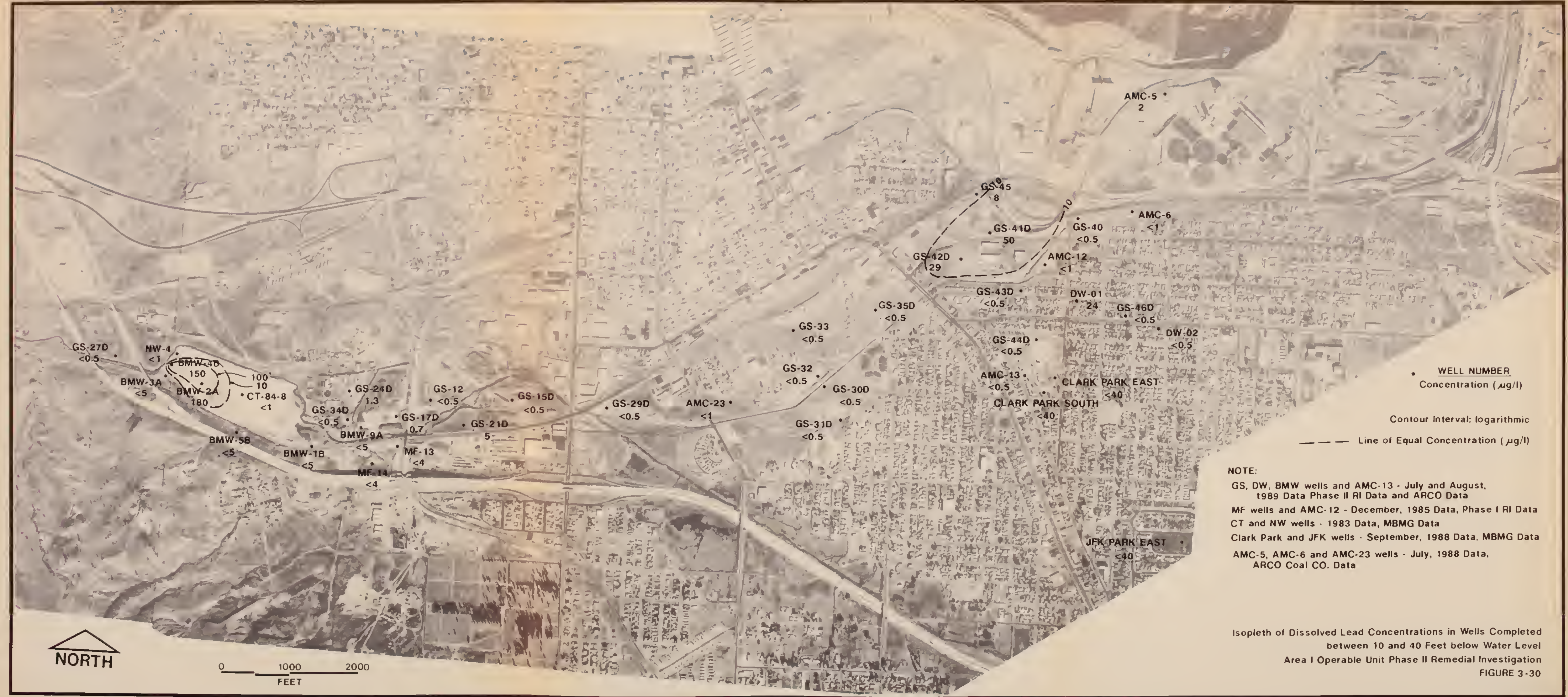
Isopleth of Dissolved Arsenic Concentrations in Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-26

Isopleth of Dissolved Cadmium Concentrations in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-27

Isopleth of Dissolved Cadmium Concentrations in Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-28



Isopleth of Dissolved Lead Concentrations
in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-29



Isopleth of Dissolved Lead Concentrations in Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-30

Isopleth of Dissolved Iron Concentrations
in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-31

Isopleth of Dissolved Iron Concentrations in Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-32

Examination of isopleth maps shown on Figures 3-21 through 3-32 indicate the following:

- There are three general source areas of elevated copper, zinc, cadmium, lead, and iron concentrations in the shallow groundwater system in the Area I Operable Unit. These include: (1) the area near the City-County shop complex more or less coincident with the historic location of the Parrott Smelter; (2) the southern cell of the Butte Reduction Works tailings impoundment; and, (3) the Colorado Tailings.

- The lateral extent of elevated metals concentrations at the latter two source areas is relatively well defined. The lateral extent of elevated metals concentrations in the area near the City-County shop area is also well defined to the east and south; however, the extent of elevated metals concentrations to the north was not determined although it appears metals are highly concentrated in the alluvium to the north at least to the alluvium-bedrock contact located just north of the baseball diamonds.

- The lateral extent of elevated metals concentrations in the alluvial groundwater system in the vicinity of the Berkeley Pit appears to be influenced by the presence of a groundwater divide caused by the presence of the pit (see Section 3.3.4). There appears to be a separate source area for copper, zinc, cadmium, and iron within the Weed Concentrator complex which may impact the quality of the alluvial groundwater moving toward the Berkeley Pit. This component of the groundwater system is represented by water quality data derived from monitoring well AMC-5.

- The primary arsenic source areas in the shallow groundwater system in Area I include: (1) the Sewage Treatment Plant area; (2) the former location of the Colorado Smelter; (3) the west end of the Colorado Tailings; and, (4) the Silver Bow Creek alluvium, west of the Colorado Tailings (Figure 3-25). Arsenic concentrations are relatively low in the deeper portion of the alluvial groundwater system at these source areas with the exception of the area at the west end of the Colorado Tailings (Figure 3-26).

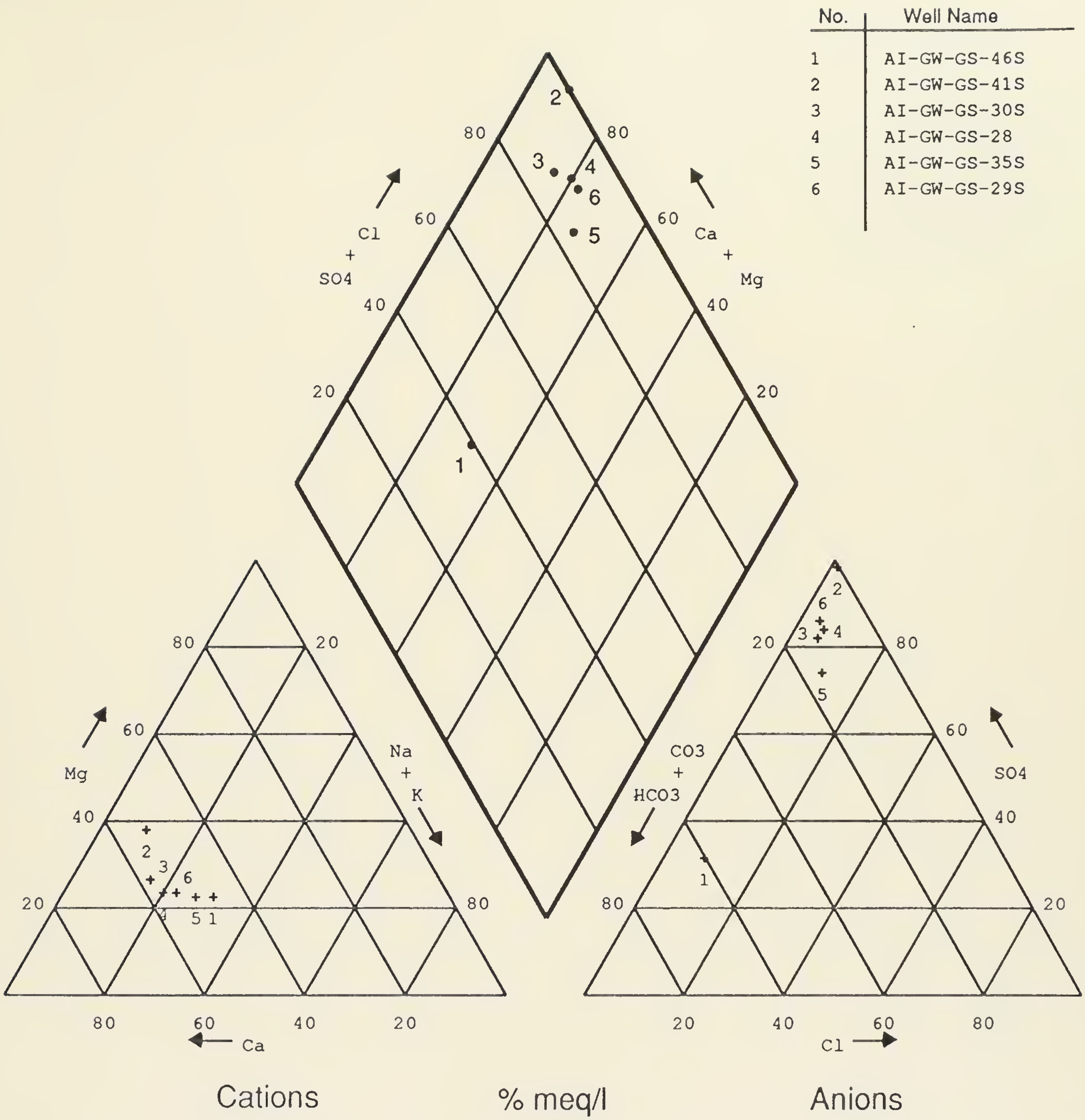
- Concentrations of dissolved metals in the shallow and deeper portions of the alluvial groundwater system generally decrease with increasing distance from identified source areas. The greatest extent of metals migration from these source areas is coincident with the direction of groundwater movement.

- Although metals concentrations generally decrease with depth in the alluvial groundwater system, the lateral extent of metals migration in the deeper (10 to 40 feet below water level) portion of the alluvial groundwater system is generally greater than in the shallow system. This is particularly apparent in the upper Metro Storm Drain area for copper (Figure 3-22), zinc (Figure 3-24), and cadmium (Figure 3-28). This phenomenon is probably related to the mobility of these particular metals and the hydraulics of groundwater movement in the Metro Storm Drain area (see Section 3.3.4). An exception to this relationship is for dissolved iron (Figures 3-31 and 3-32) where the lateral extent of iron migration in the shallow and deeper components of the groundwater is approximately the same.

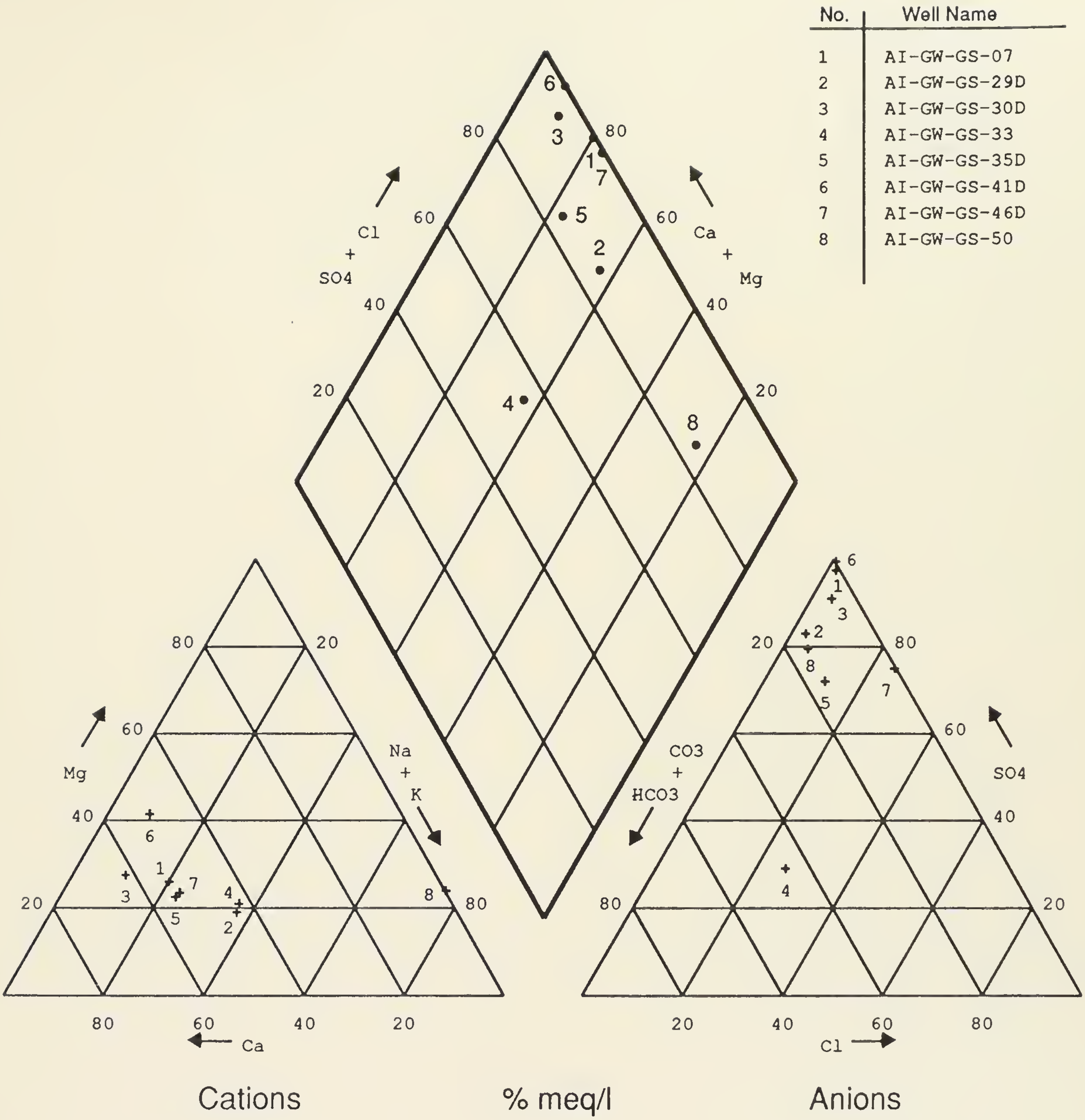
- Dissolved lead in the Area I alluvial groundwater system occurs in the three general source areas; however, the lateral and vertical migration of lead appears to be limited.

- Metals which appear to exit the Area I Operable Unit via the Silver Bow Creek alluvial system west of the Colorado Tailings include zinc (Figures 3-23 and 3-24), arsenic (Figures 3-25 and 3-26), and iron (Figures 3-31 and 3-32). In the case of arsenic, there is some indication that a separate source located west of the Colorado Tailings may contribute to the occurrence of arsenic in the shallow groundwater system west of the Colorado Tailings.

Figures 3-33 through 3-38 are trilinear diagrams of common ions measured in samples collected from shallow (upper 10 feet) and deeper (between 10 and 40 feet below water level) wells in the Metro Storm Drain, Butte Reduction Works, and Colorado Tailings areas. Figures 3-39 and 3-40 are maps showing stiff diagrams from selected wells completed in the shallow and deeper portions of the alluvial groundwater system in Area I, respectively.



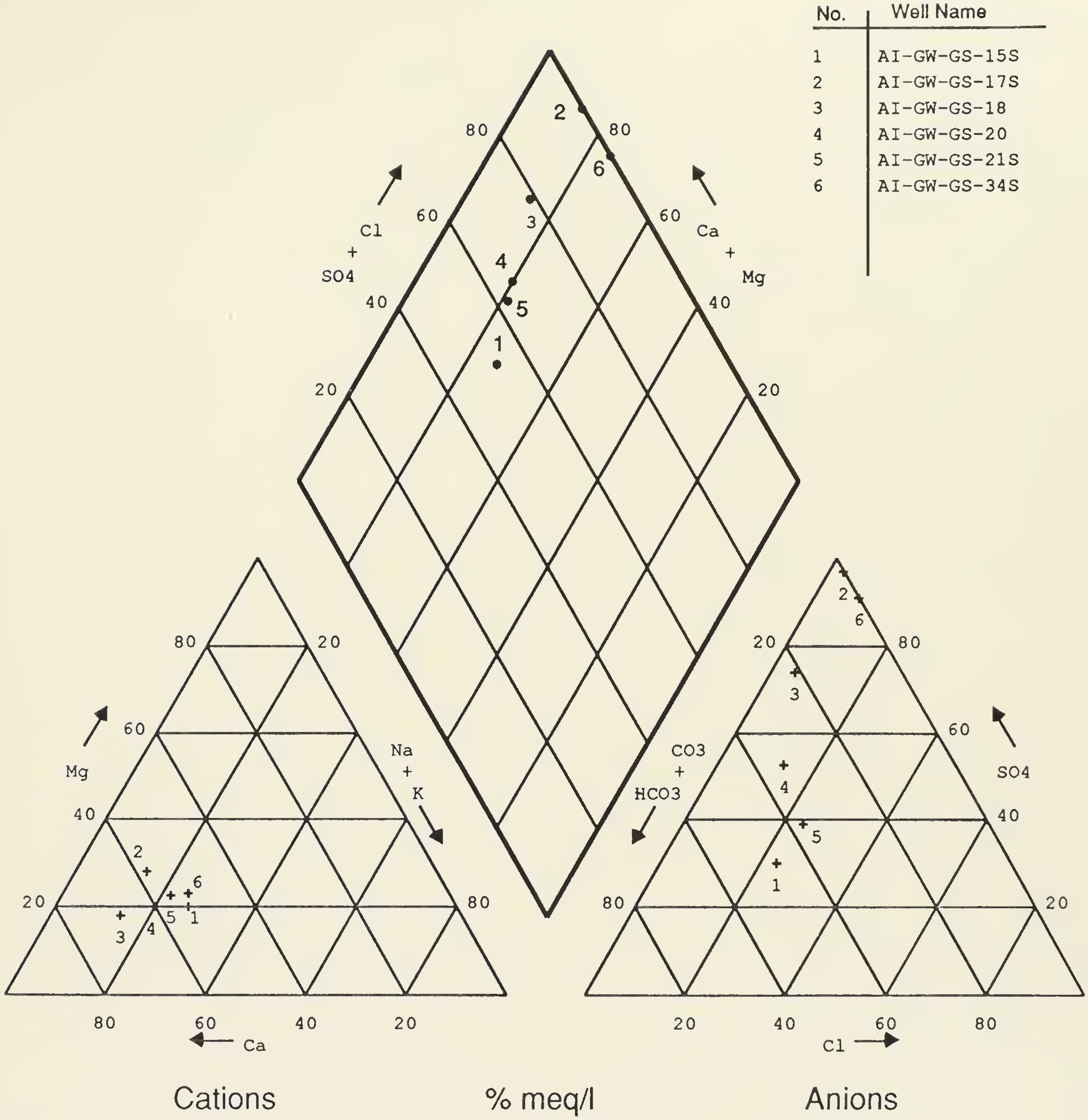
Trilinear Diagram of Monitoring Wells Completed in the Upper 10 Feet of the Alluvial Groundwater System in the Metro Storm Drain Area (August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-33



Trilinear Diagram of Monitoring Wells Completed between 10 and 40 Feet below Water Level in the Metro Storm Drain Area (August, 1989 Data)

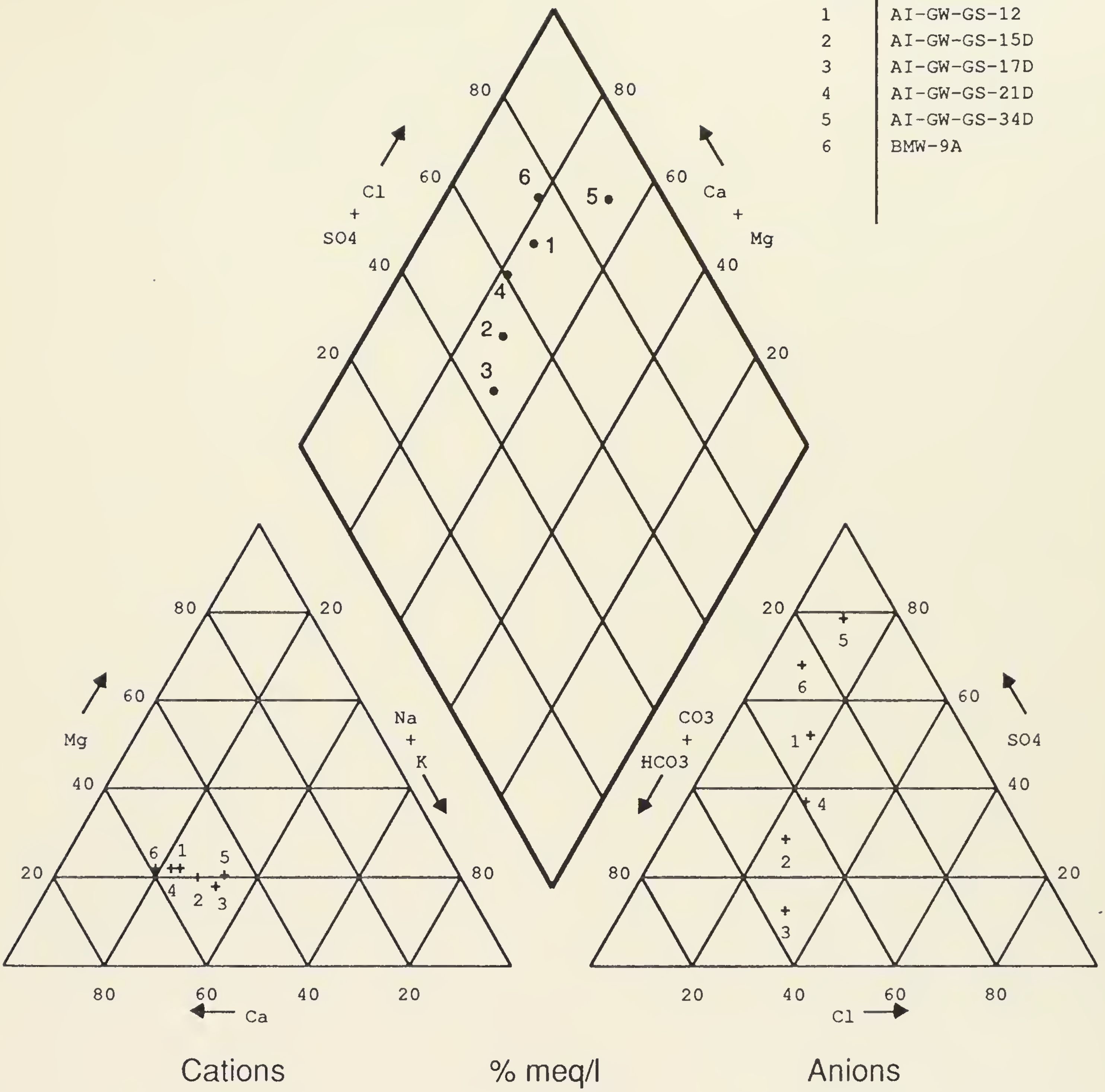
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-34

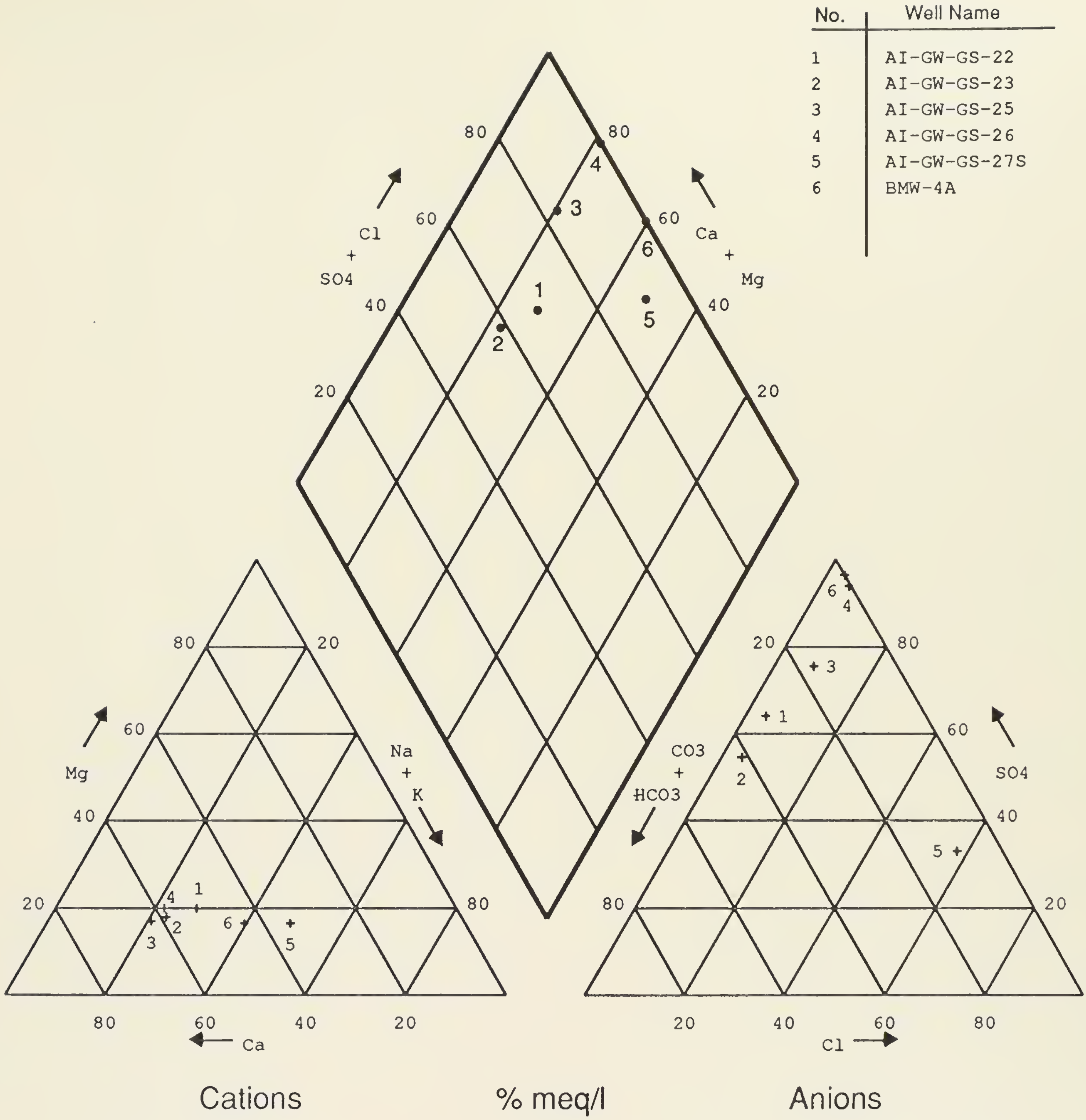


Trilinear Diagram of Monitoring Wells Completed in the Upper 10 Feet of the Alluvial Groundwater System in the Butte Reduction Works Area (August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-35

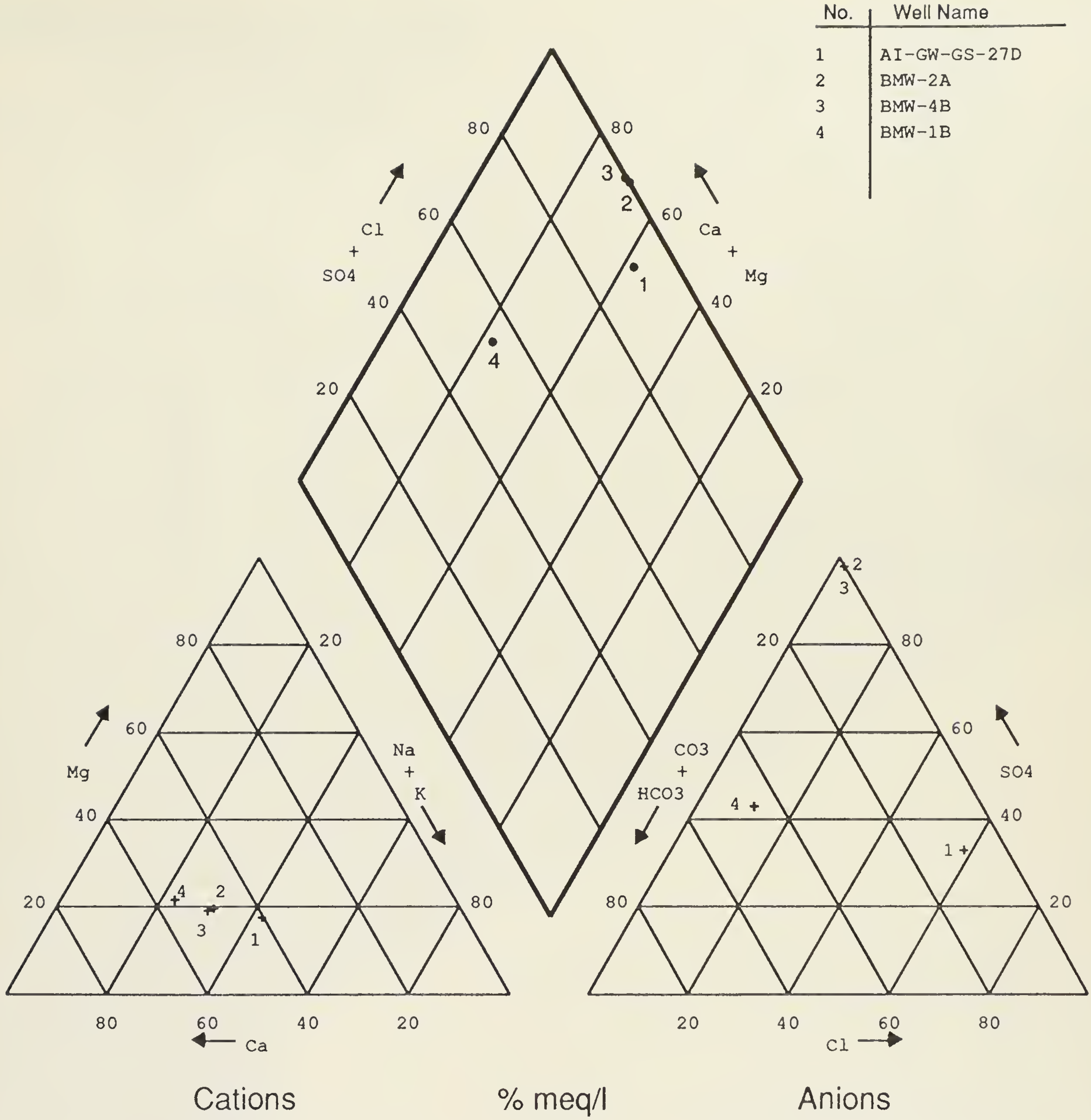
No.	Well Name
1	AI-GW-GS-12
2	AI-GW-GS-15D
3	AI-GW-GS-17D
4	AI-GW-GS-21D
5	AI-GW-GS-34D
6	BMW-9A



Trilinear Diagram of Monitoring Wells Completed between 10 and 40 Feet below Water Level in the Butte Reduction Works Area (August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-36



Trilinear Diagram of Monitoring Wells Completed in the Upper 10 Feet of the Alluvial Groundwater System in the Colorado Tailings Area (August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-37



Trilinear Diagram of Monitoring Wells Completed between 10 and 40 Feet below Water Level in the Colorado Tailings Area (August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-38

Map Showing Stiff Diagrams for Selected Monitoring Wells Completed in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-39

Map Showing Stiff Diagrams for Selected Monitoring Wells Completed between 10 and 40 Feet below Water Level in the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-40

These figures indicate the following:

- Water in both shallow and deeper portions of the alluvial groundwater system proximal to the Metro Storm Drain is typically a calcium sulfate type (Figures 3-33, 3-34,3-39, and 3-40). Blacktail Creek alluvial groundwater also exhibits a calcium sulfate type water as measured in monitoring well AI-GW-GS-28 (Figure 3-39) The wells exhibiting the largest ionic strength within this area are AI-GW-GS-41S and AI-GW-GS-41D which are both located just north of the City-County shop complex (Figures 3-39 and 3-40). Groundwater east and upgradient of the Metro Storm Drain exhibits a calcium bicarbonate type water of low ionic strength. Monitoring well AI-GW-GS-50, completed to a depth of 268 feet below ground surface, contains water which groups separately from other shallower wells as a sodium sulfate type water (Figure 3-34).

- Groundwater in both shallow and deeper portions of the groundwater system between Montana Street and the Butte Reduction Works tailing impoundments exhibit a low ionic strength calcium bicarbonate or calcium sulfate water type which is relatively unique with respect to adjacent areas (Figures 3-35, 3-36, 3-39, and 3-40).

- Groundwater in the vicinity of the Butte Reduction Works tailing impoundments area and the Colorado Tailings is typically a calcium sulfate type water of relatively high ionic strength (Figures 3-37, 3-38, 3-39, and 3-40). Wells completed south of and upgradient from the Colorado Tailings (e.g. BMW-1B) exhibit water quality which groups separately from those completed within the Colorado Tailings (Figures 3-37 and 3-38), and in some cases, the water is a calcium bicarbonate type.

- Groundwater in the Silver Bow Creek alluvial aquifer west of the Colorado Tailings is a sodium chloride type water. This is typified by monitoring wells AI-GW-GS-27S and AI-GW-GS-27D (Figures 3-39 and 3-40). This type of water quality is unique with respect to other wells sampled in Area I.

Ion data indicate those areas which exhibit high concentrations of dissolved metals are generally associated with a calcium sulfate type water. Likewise, those portions of the groundwater system which exhibit low metals concentrations typically are associated with a calcium bicarbonate type water.

An isopleth of sulfate concentrations in the shallow (upper 10 feet) and deeper (between 10 and 40 feet below water level) portions of the Area I alluvial groundwater system is shown on Figures 3-41 and 3-42, respectively. These isopleths indicate that most groundwater in the shallow portions of the alluvial groundwater system in Area I exhibit sulfate concentrations greater than 500 mg/L with the exception of the area between Montana Street and the Butte Reduction Works tailing impoundments. Highest sulfate concentrations in shallow alluvial groundwater system are located near the City-County shop complex, in the Butte Reduction Works tailings impoundments area, and in the west end of the Colorado Tailings (Figure 3-41).

The extent of groundwater exhibiting sulfate concentrations above 500 mg/L in the Metro Storm Drain area is slightly greater in the deeper (10 to 40 feet below water level) portions of the alluvial groundwater system as compared to the upper 10 feet of the aquifer (Figure 3-42). Sulfate concentrations are less than 500 mg/L in the deeper portions of the groundwater system underlying the Butte Reduction Works tailings impoundments (Figure 3-42). The extent of sulfate concentrations greater than 1000 mg/L in the Colorado Tailings area is greater in the deeper portion of the alluvial groundwater system as compared to the shallow system (Figure 3-42).

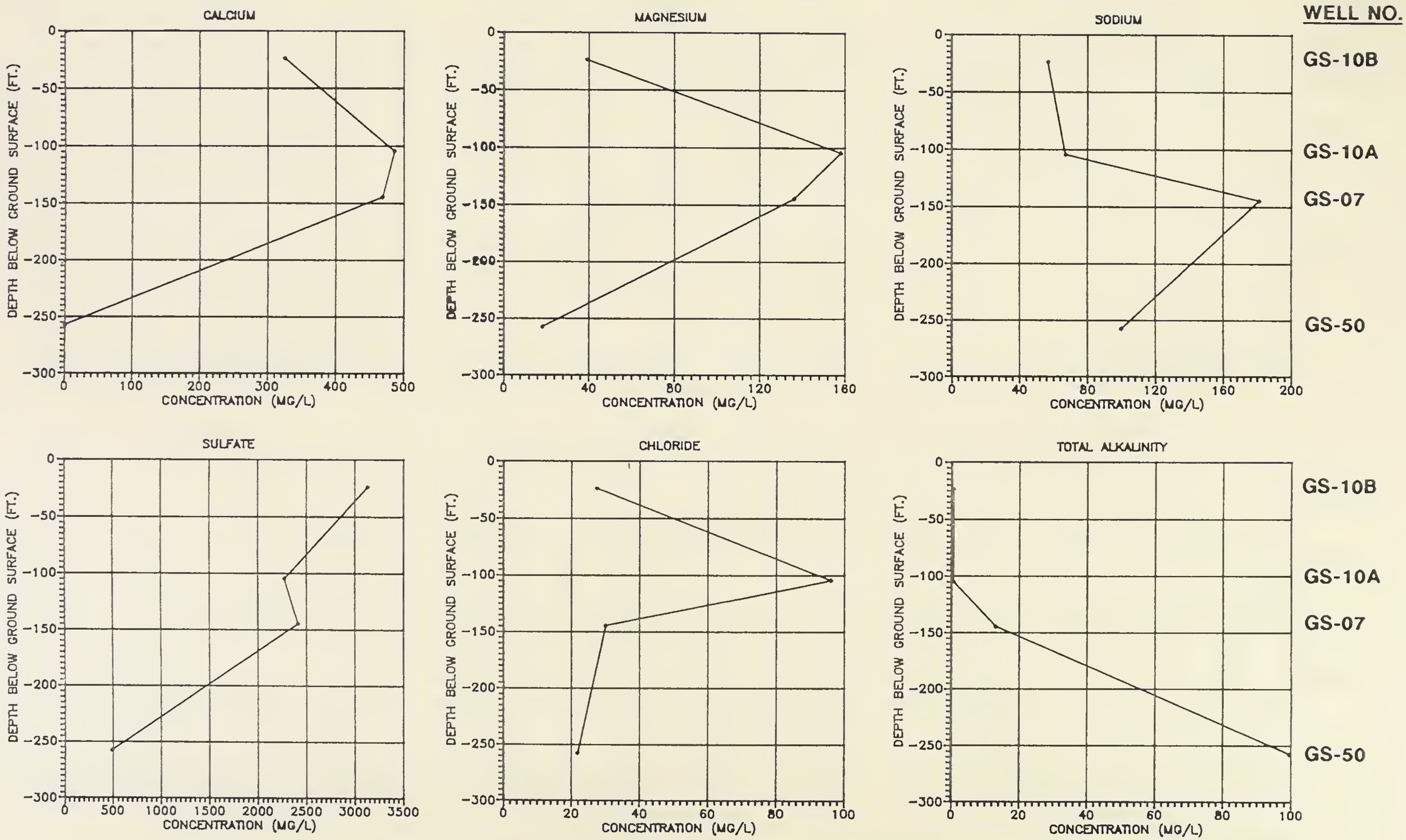
The vertical distribution of common ions in the groundwater system in the upper Metro Storm Drain area, the lower Metro Storm Drain area, the Butte Reduction Works tailing impoundments area, and the Colorado Tailings is illustrated on Figures 3-43, 3-44, 3-45, and 3-46, respectively. Major ions in groundwater near the upper end of the Metro Storm Drain generally increase in concentration to a depth of about 100 feet below ground surface and then decrease to relatively low concentrations at depths greater than 200 feet below ground surface (Figure 3-43). Alkalinity concentrations remain low to depths of approximately 100 feet below ground surface and increase by nearly two orders of magnitude at depths below 200 feet (Figure 3-43).

Isopleth of Sulfate Concentrations in Monitoring Wells Completed in the Upper 10 Feet of the Alluvial Groundwater System
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-41

Isopleth of Sulfate Concentrations in Monitoring Wells Completed between 10 and 40 Feet below Water Level
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-42

(August, 1989 Data)

Vertical Distribution of Major Ions in Groundwater in the Vicinity of the City-County Shop Complex

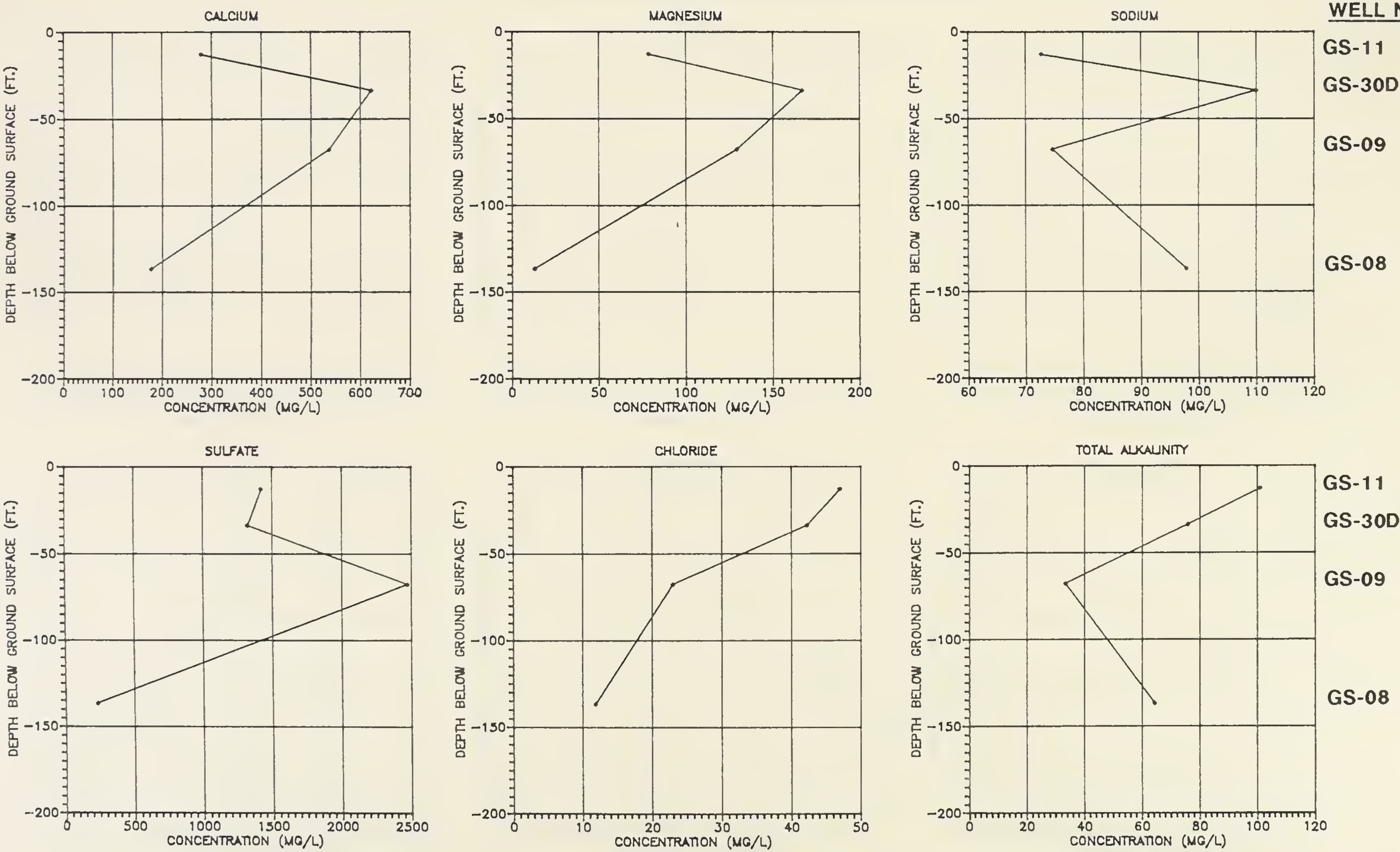


Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-43

(August, 1989 Data)

Vertical Distribution of Major Ions in Groundwater in the Vicinity of Kaw Avenue



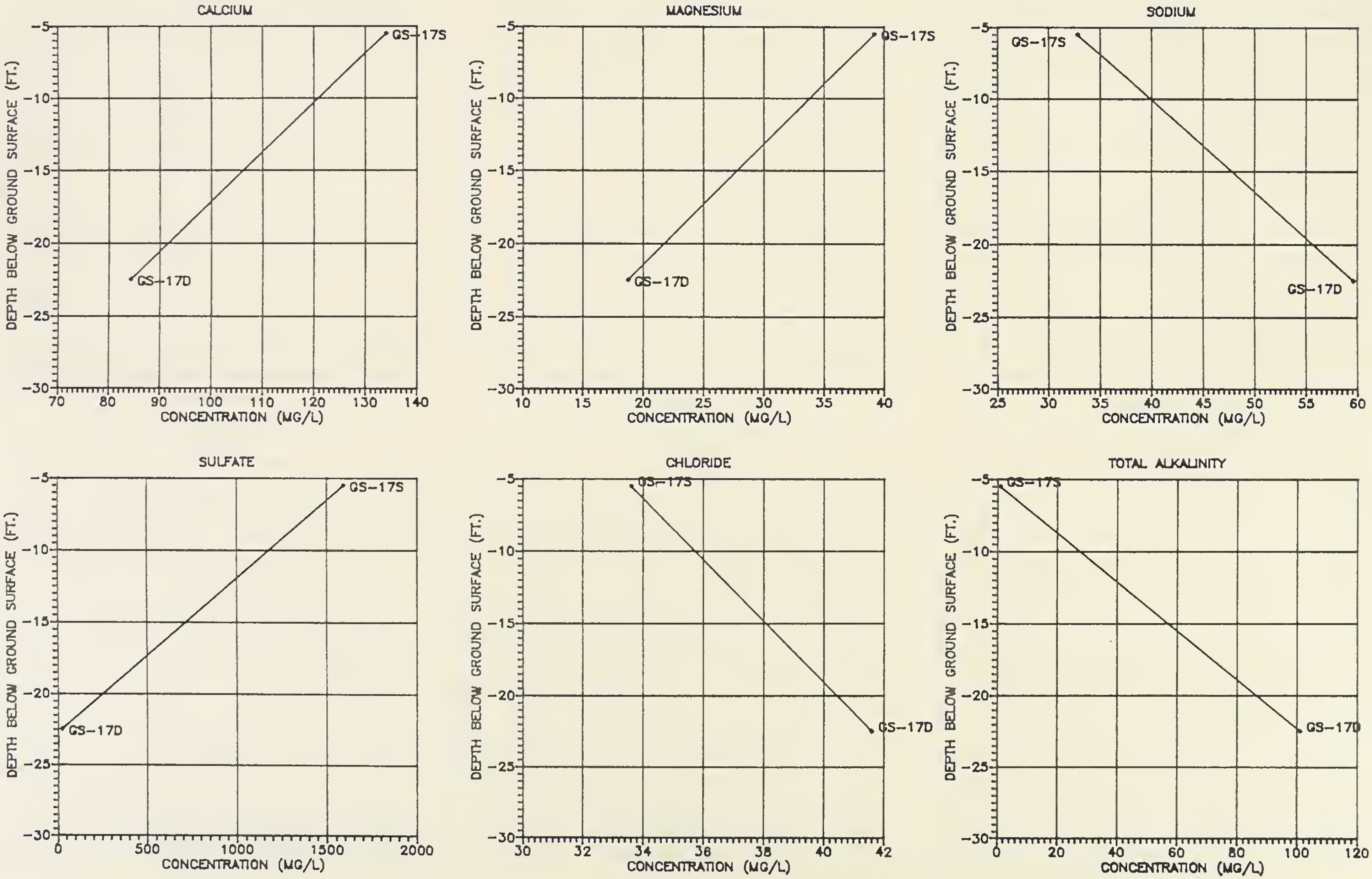
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-44

(August, 1989 Data)

Vertical Distribution of Major Ions in Groundwater

in the Butte Reduction Works Tailing Impoundments Area

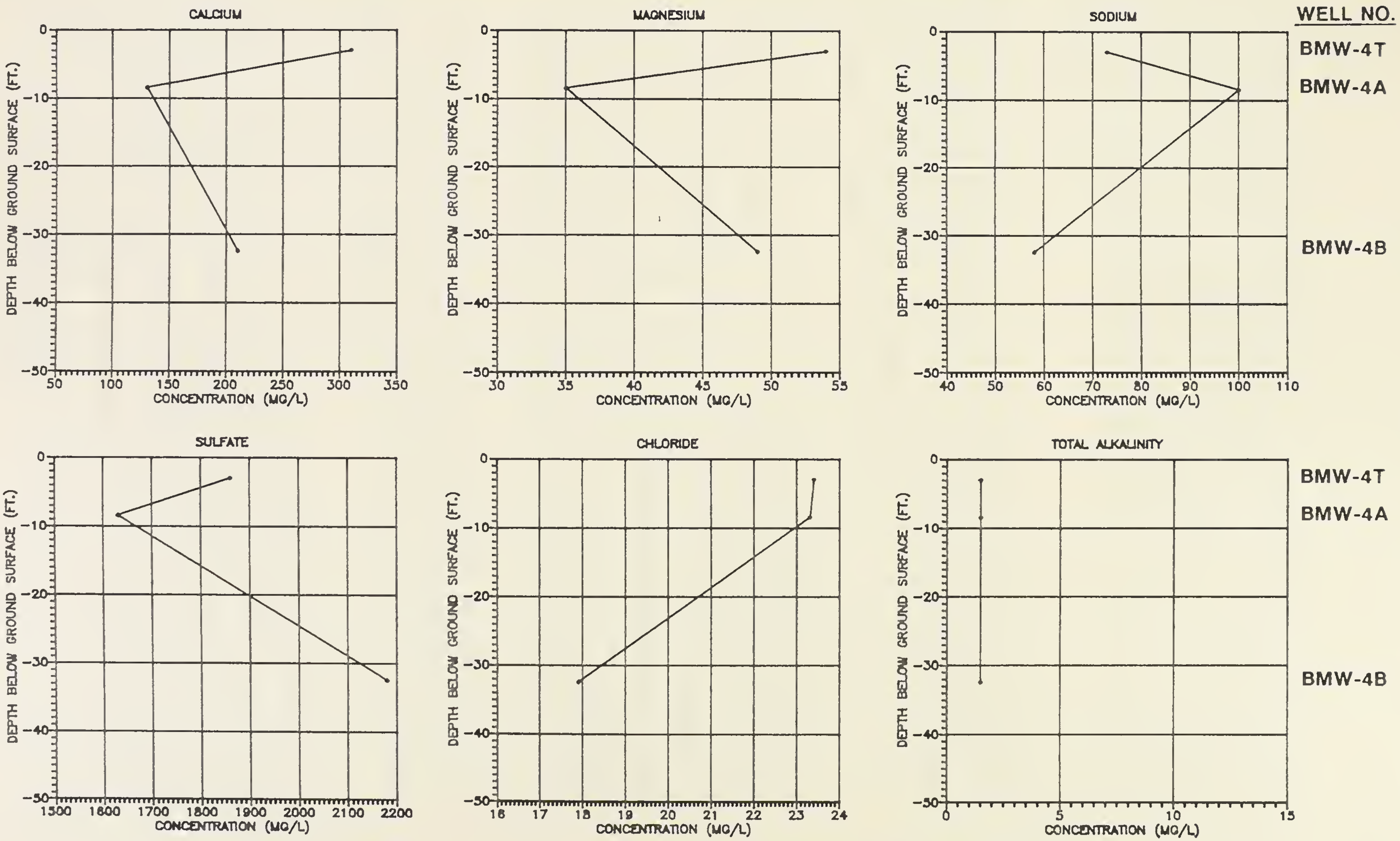


Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-45

(August, 1989 Data)

Vertical Distribution of Major Ions in Groundwater in the Colorado Tailings



Area Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-46

Concentrations of major ions in groundwater near the lower end of the Metro Storm Drain near Kaw Avenue generally increase vertically from the top of the groundwater system to a depth of approximately 50 feet below ground surface (Figure 3-44). Below 50 feet, concentrations generally decrease to relatively low levels. Alkalinity concentrations exhibit an inverse relationship to most other ions; concentrations appear to decrease from near the top of the aquifer to depths of 50 to 60 feet below ground surface and then increase with depth (Figure 3-44).

Vertical relationships for major ions in the vicinity of the Butte Reduction Works tailing impoundments area indicate calcium, magnesium, and sulfate decrease measurably with depth in the alluvial groundwater system while sodium, chloride and total alkalinity increase with depth (Figure 3-45). These trends are unique with respect to vertical variations in ion concentrations measured elsewhere within the study area.

Vertical trends in major ions at the west end of the Colorado Tailings are illustrated on Figure 3-46. These plots indicate that calcium, magnesium, and sulfate concentrations decrease and concentrations of sodium increases from the upper portion of the alluvial aquifer to the lower portion of the alluvial groundwater system. An inverse relationship in trends of these parameters occurs from the lower portion of the alluvial groundwater system into the underlying bedrock system. Chloride concentrations generally decrease with depth in groundwater system beneath the Colorado Tailings. Total alkalinity was less than 3 mg/L in all three zones of the groundwater system sampled at the Colorado Tailings.

In general, major ion concentrations relate directly to metals concentrations in Area I groundwater. Groundwater exhibiting relatively high metals concentrations generally contains relatively high calcium, magnesium, and sulfate concentrations and relatively low total alkalinity concentrations and pH values.

Table 3-4 summarizes Federal primary and secondary drinking water standard exceedances for wells sampled in conjunction with the Phase II RI during August, 1989. Exceedances of primary standards for arsenic, cadmium, lead, nitrate + nitrite, and fluoride occurred in one or more of the wells sampled. The parameters which most frequently exceeded primary drinking water standards were cadmium and lead. Parameters which most frequently exceeded secondary standards in wells sampled included copper, iron, manganese, zinc, sulfate, and pH.

TABLE 3-4

SUMMARY OF PRIMARY AND SECONDARY DRINKING WATER STANDARD EXCEEDANCES, AUGUST, 1989 DATA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

	Primary Standard Exceedance (2)										Secondary Standard Exceedance (3)						
Well No.(1)	As	Cd	Pb	Cr	Ba	Hg	Se	Ag	Nitrate as N	F(4)	Cl	Cu	Fe	Mn	pH	SO_4	Zn
DW-01		X										X	X	X	X		X
DW-02									X					X	X		
GS-07		X										X	X	X	X	X	X
GS-08														X			
GS-09		X										X		X	X	X	X
GS-10D		X								X		X	X	X	X	X	X
GS-10S		X	X									X	X	X	X	X	X
GS-11		X	X									X	X	X		X	X
GS-12		X												X			
GS-13A		X	X											X		X	X
GS-14		X												X		X	
GS-15D														X			
GS-15S															X		
GS-16		X								X				X		X	X
GS-17D														X			
GS-17S		X	X							X		X	X	X	X	X	X
GS-18		X										X		X		X	X
GS-19		X	X										X	X	X		X
GS-20																	
GS-21D														X			
GS-21S														X			
GS-22	X															X	
GS-23																	
GS-24D		X												X		X	
GS-24S	X	X												X		X	X
GS-25		X								X				X		X	X
GS-26		X	X									X	X	X	X	X	X
GS-27D	X										X		X	X	X	X	
GS-27S	X									X	X		X	X	X	X	
GS-28													X	X	X	X	
GS-29D														X		X	
GS-29S														X		X	
GS-30D		X											X	X	X	X	
GS-30S													X	X	X	X	
GS-31D														X	X	X	
GS-31S														X		X	
GS-32		X												X	X	X	X

TABLE 3-4 (continued)

SUMMARY OF PRIMARY AND SECONDARY DRINKING WATER STANDARD EXCEEDANCES, AUGUST, 1989 DATA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

	Primary Standard Exceedance (2)										Secondary Standard Exceedance (3)						
Well No.(1)	As	Cd	Pb	Cr	Ba	Hg	Se	Ag	Nitrate as N	F(4)	Cl	Cu	Fe	Mn	pH	SO_4	Zn
GS-33		X												X			
GS-34D		X											X	X	X	X	X
GS-34S		X	X									X	X	X	X	X	X
GS-35D		X												X	X	X	X
GS-35S		X												X	X	X	X
GS-40		X											X	X	X	X	X
GS-41D		X	X							X		X	X	X	X	X	X
GS-41S		X	X							X		X	X	X	X	X	X
GS-42D		X								X		X	X	X	X	X	X
GS-42S		X								X		X	X	X	X	X	X
GS-43D		X										X	X	X	X	X	X
GS-43S		X								X		X		X	X	X	X
GS-44D		X										X		X	X	X	X
GS-44S		X										X		X	X		X
GS-45		X								X		X		X	X	X	X
GS-46D														X	X		
GS-46S														X			
GS-50														X		X	
AMC-13		X											X	X	X	X	

NOTES: (1) Well locations shown on Exhibit I. Prefix to "GS" wells (AI-GW) has been dropped. "S" indicates shallow, and "D" indicates deeper well completion at same site.

(2) EPA National Interim Primary Drinking Water Standards. 40 CFR 141, No. 248, December 24, 1975.

Standards: As (50 μg/L); Cd (10 μg/L); Pb (50 μg/L); Cr (50 μg/L); Ba (1,000 μg/L); Hg (2 μg/L); Se (10 μg/L); Ag (50 μg/L); Nitrate as N (10 mg/L)

(3) EPA National Interim Secondary Drinking Water Standards. 40 CFR 143, No. 140, July 19, 1979.

Standards: Cl (250 mg/L); Cu (1 mg/L); Fe (0.3 mg/L); Mn (0.05 mg/L); pH (6.5-8.5 s.u.); SO_4 (250 mg/L); Zn (5 mg/L)

(4) Exceedance of threshold concentration of 4.0 mg/L.

Figure 3-47 shows the approximate lateral extent of the shallow groundwater system (upper 10 feet) in Area I which exceeds one or more primary drinking water standards. The total area associated with primary drinking water standard exceedances in the shallow alluvial aquifer in Area I is approximately 300 acres.

The extent of primary drinking water standard exceedances in the deeper portion of the alluvial groundwater system (between 10 and 40 feet below water level) is illustrated in Figure 3-48. The area associated with primary drinking water standard exceedances in this portion of the groundwater system is approximately 400 acres.

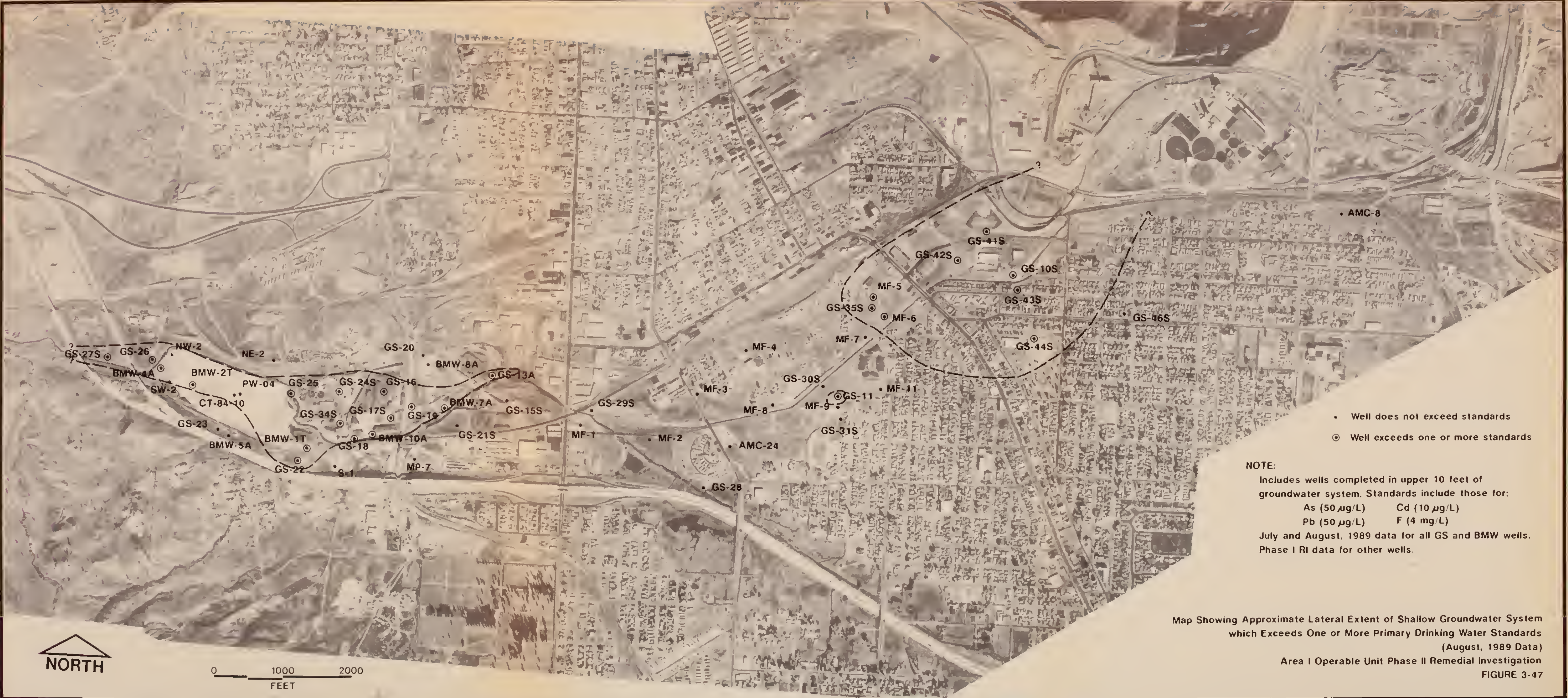
It is probable the greater areal extent of primary drinking water exceedances in the deeper portion of the groundwater system as compared to the shallower part is related to the pathways of groundwater movement with respect to metals source areas in Area I. Further discussion of this concept is presented in Sections 3.3.4 and 6.0.

3.3.4 Groundwater Movement

Monthly water level data for monitored wells in Area I from August, 1989 through January, 1990 are included in Appendix B-5. Monitoring well measuring point elevations determined through a land survey completed during the Phase II RI are also included in Appendix B-5.

Figure 3-49 is a water table map of the Area I Operable Unit based on January, 1990 groundwater elevation data. Examination of Figure 3-49 indicates the alluvial groundwater system is nearly flat in the upper reaches of Area I, below the Weed Concentrator. Sources of groundwater recharge to the operable unit include the area to the east, south of the Berkeley Pit, the Blacktail Creek alluvium, Butte Hill, and the foothills south of the Colorado Tailings. Other recharge sources in the area may include direct infiltration of precipitation and possibly seepage from unlined ponds in the vicinity of the Weed Concentrator.

A divide in the alluvial groundwater system is evident near the upper end of the Metro Storm Drain area. This divide is caused by the presence of the Berkeley Pit which drains a portion of the adjacent alluvial groundwater system. The radius of influence the Berkeley Pit exerts on the alluvial groundwater system appears to be about 2000 feet in the vicinity



NOTE:
Includes wells completed in upper 10 feet of groundwater system. Standards include those for:
As (50 μg/L) Cd (10 μg/L)
Pb (50 μg/L) F (4 mg/L)
July and August, 1989 data for all GS and BMW wells.
Phase I RI data for other wells.

Map Showing Approximate Lateral Extent of Shallow Groundwater System which Exceeds One or More Primary Drinking Water Standards (August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-47

Map Showing Approximate Lateral Extent of Deeper Groundwater System
which Exceeds One or More Primary Drinking Water Standards
(August, 1989 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-48

Water Table Map of Area I Operable Unit
(January, 1990 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-49

of the Weed Concentrator (Figure 3-49). The proximity of the groundwater divide in the alluvium to the pit rim suggests the alluvial material in the vicinity of the Weed Concentrator and the City-County shop complex exhibits relatively low permeability. This inference is further supported by pumping tests completed in the vicinity of the City-County shop complex (see Section 3.3.5).

Shallow groundwater movement in the vicinity of the Metro Storm Drain is generally parallel to the drain to the southwest. The lateral groundwater gradient associated with this portion of the operable unit is approximately 0.3%. The shallow system intercepts the base of the Metro Storm Drain just southwest of Harrison Avenue resulting in perennial flow in the storm drain below this location. The groundwater gradient appears to flatten somewhat near the confluence of the Metro Storm Drain and Blacktail Creek to about 0.1%.

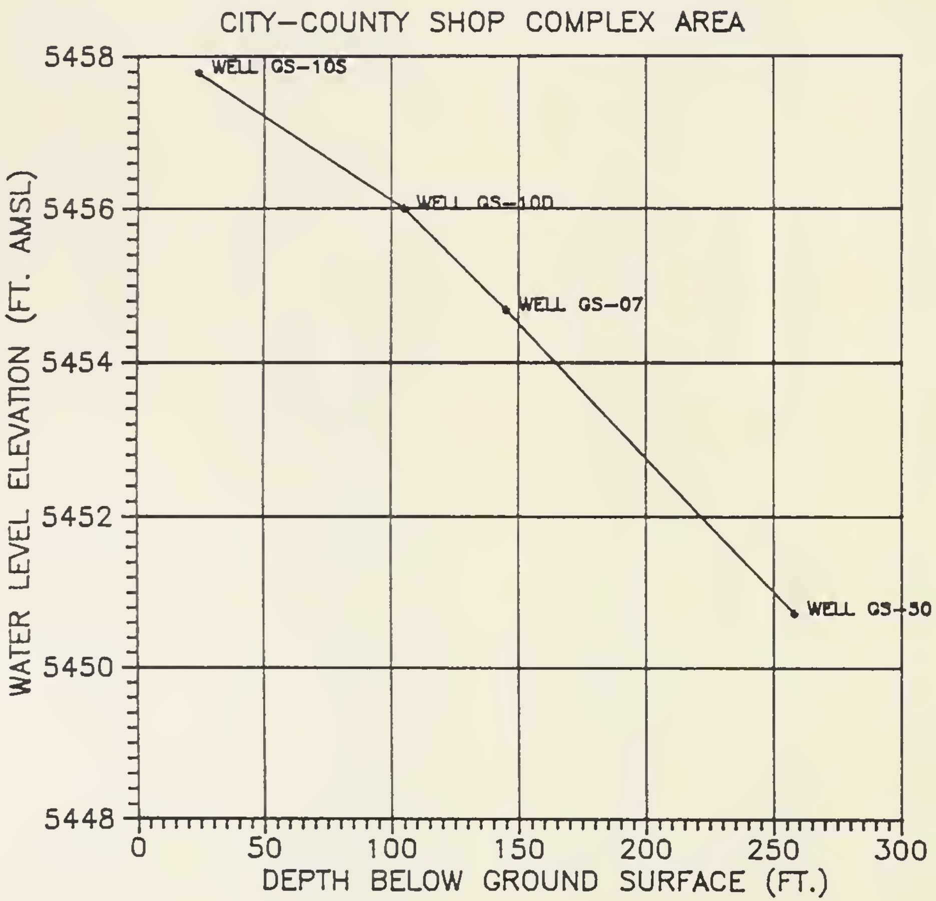
A separate component of groundwater enters the operable unit from the southeast. This system is associated with the Blacktail Creek alluvium. Although the gradient of this groundwater system was not measured during the RI, previous investigators of this area (Botz, 1969 and Meinzer, 1915) report the gradient to be approximately 0.3%.

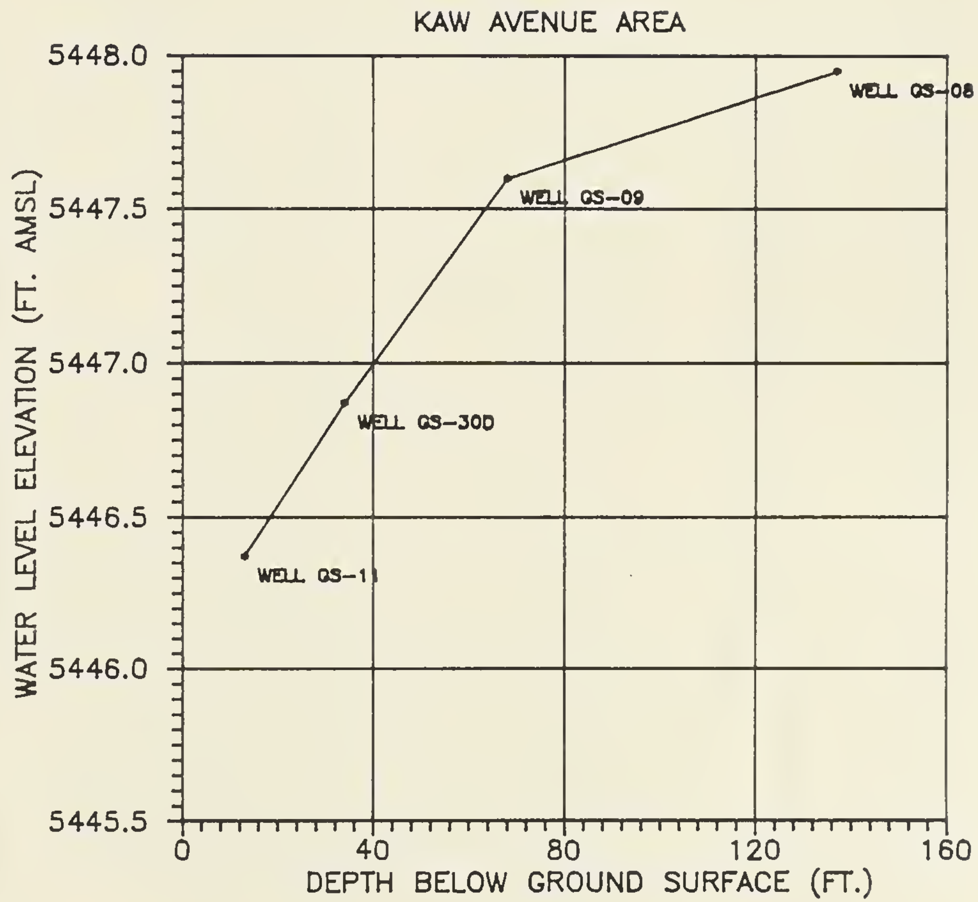
Groundwater movement in the lower portions of Area I (from Montana Street to below the Colorado Tailings) is generally to the west and toward Silver Bow Creek. Water level data indicate Silver Bow Creek gains flow from groundwater input in this area; groundwater flow lines are typically toward the stream (Figure 3-49). The groundwater gradient in this portion of the operable unit is approximately 0.2%. The data also indicate that the lower portion of Area I receives groundwater input from both the south (in the vicinity of the historic Montana Pole and Treatment Plant site) and the north (Missoula Gulch area). The relationships between these various systems were not determined during the RI; these types of evaluations are being completed in conjunction with the Montana Pole RI/FS and studies of mine flooding in the Butte Hill.

Multiple well completions at various depths in Area I provide an indication of the vertical component to groundwater movement at the operable unit. Figure 3-50 illustrates water level elevations at various depths in the vicinity of the City-County shop complex and near Kaw Avenue. These data indicate a downward gradient is present in the upper reaches of the operable unit near the City-County shop complex; the magnitude of this gradient is on

(January, 1990 Data)

Vertical Profile of Water Level Elevations





Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-50

the order of 3%. The vertical component to groundwater movement near the center portion of the Metro Storm Drain area (Figure 3-50) is upward at a gradient of approximately 1%.

The downward component to groundwater movement in the upper reaches of the Metro Storm Drain may be caused by one or more of the following mechanisms:

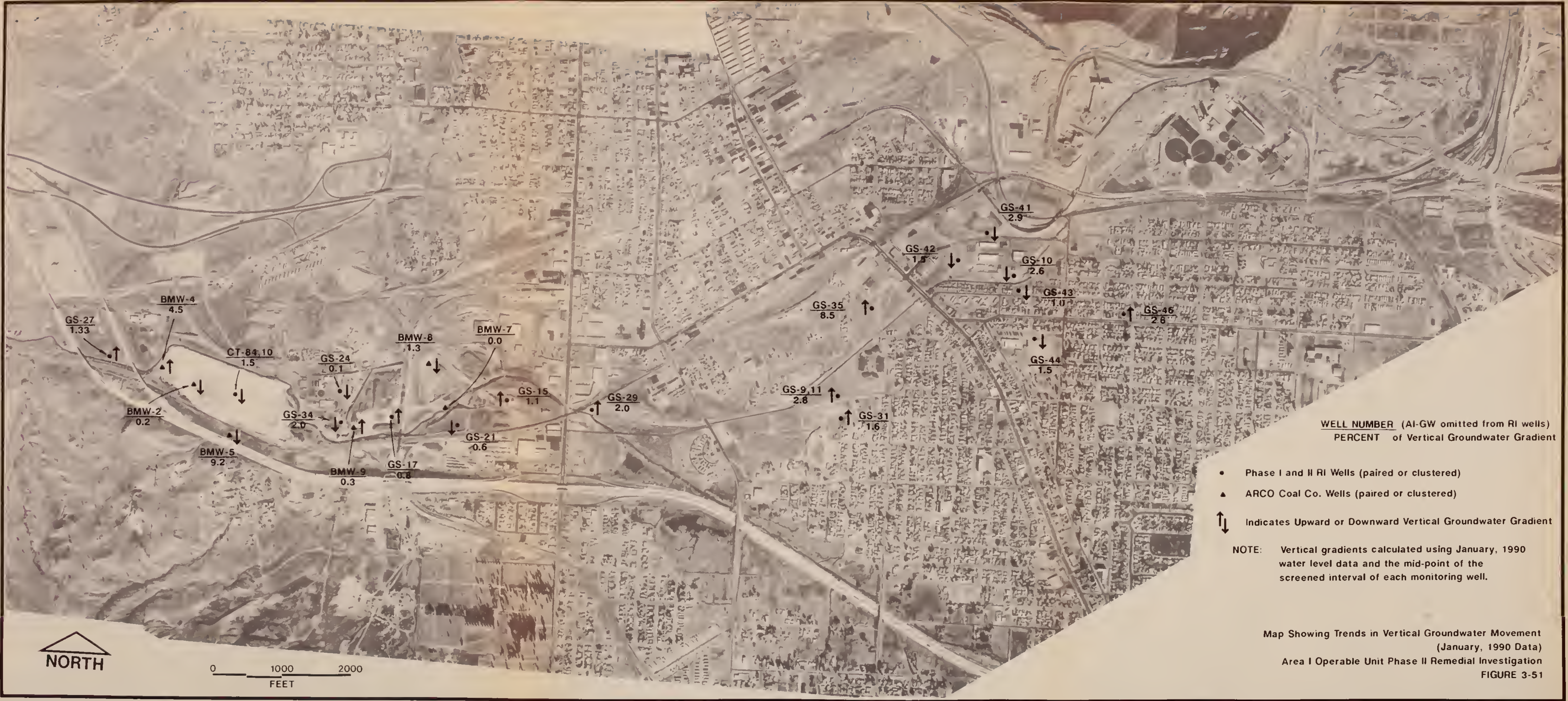
- The presence of a relatively high permeability unit at depth in which groundwater is transmitted at a rate higher than the rate of recharge to the unit. A highly permeable zone was encountered during drilling of monitoring well AI-GW-GS-50 (Figure 3-10) at a depth of about 210 feet below ground surface.

- A dewatered bedrock system below the saturated alluvial groundwater system. This situation would create the potential for gravity drainage of the alluvial groundwater system. It is possible that historic pumping from the Kelley shaft dewatered the bedrock system for a greater lateral distance than the overlying alluvial groundwater system. Data to characterize this potential dual groundwater divide system were not collected during this investigation.

- Leakage from unlined process ponds at the Weed Concentrator complex. This source of recharge to the groundwater system may create a groundwater mound which is affecting groundwater levels in the upper Metro Storm Drain area.

The upward gradient measured near the middle reaches of the Metro Storm Drain (Figure 3-50) is indicative of confining conditions in the area. This may be the result of a decrease in permeability of deeper sediments laterally, to the southwest or a decrease in the thickness of saturated sediments. A decrease in permeability in this area is suggested by relatively fine grained lithologies encountered at depths of 80 to 100 feet below surface at monitoring well AI-GW-GS-08 (Figure 3-11).

Figure 3-51 illustrates the direction and magnitude of vertical groundwater movement in Area I. It appears groundwater recharge areas are present in the upper Metro Storm Drain and to the south of the Colorado Tailings. Groundwater discharge areas are identifiable in the central and lower portions of the Metro Storm Drain area and at the west end of the



Map Showing Trends in Vertical Groundwater Movement
(January, 1990 Data)
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-51

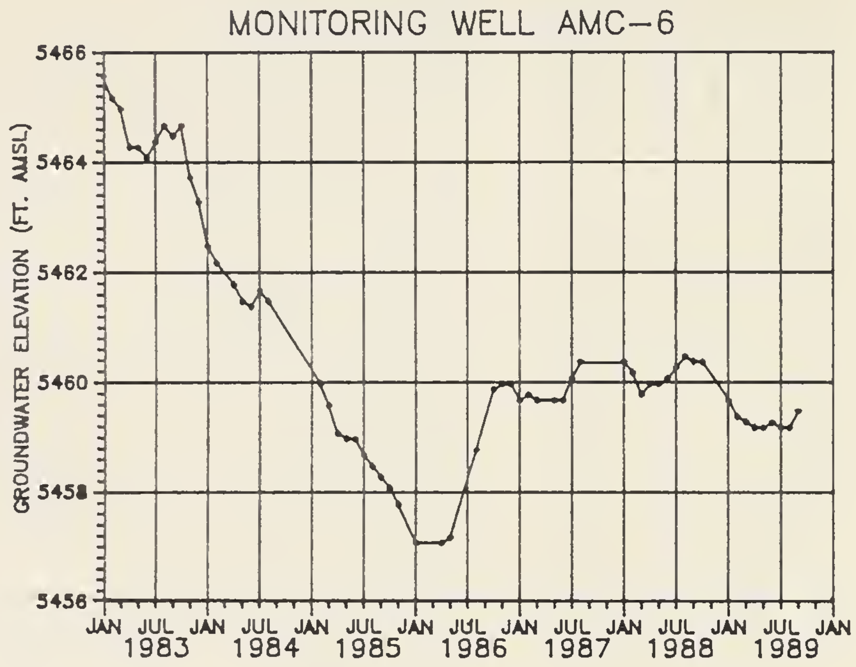
Colorado Tailings and to the west of the Colorado Tailings. There does not appear to be a definitive direction of vertical groundwater movement in the area between Montana Street and the Colorado Tailings (Figure 3-51).

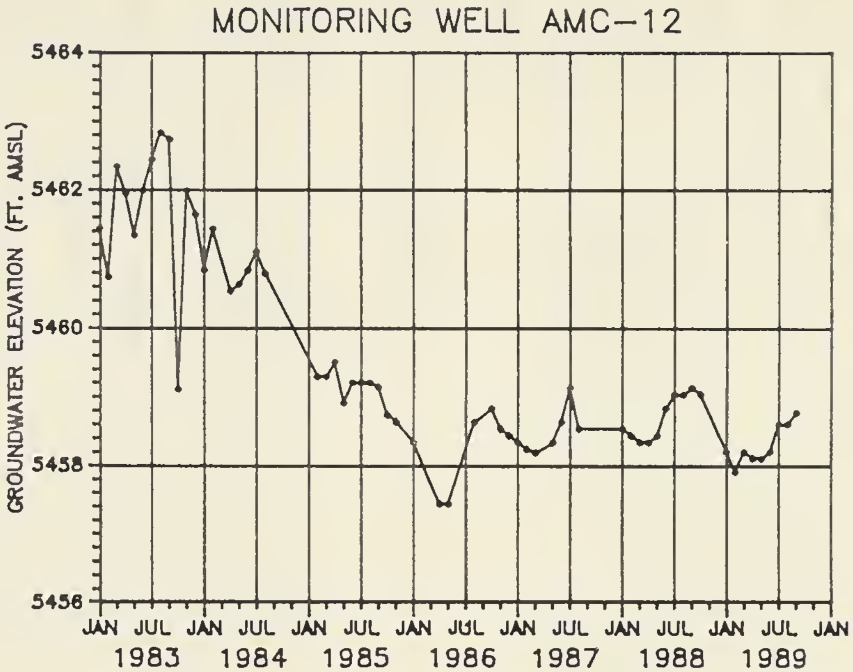
Temporal trends in groundwater elevations measured in monitoring wells AMC-6, AMC-12, and AMC-24 are illustrated on Figure 3-52. Monitoring well AMC-6 is located just south of the Weed Concentrator complex, monitoring well AMC-12 is located near the City-County shop complex, and monitoring well AMC-24 is located in the lower Metro Storm Drain area (Exhibit I). Examination of Figure 3-52 indicates water levels in monitoring wells AMC-6 and AMC-12 declined about nine feet and five feet, respectively, from early 1983 to early 1986. During this same time period, water levels in monitoring well AMC-24 were generally stable. Water levels in monitoring wells AMC-6 and AMC-12 began to rise in 1986 until early to mid-1987 while water levels remained relatively consistent in monitoring well AMC-24 (Figure 3-52). Water levels in all three wells have remained relatively stable since 1987.

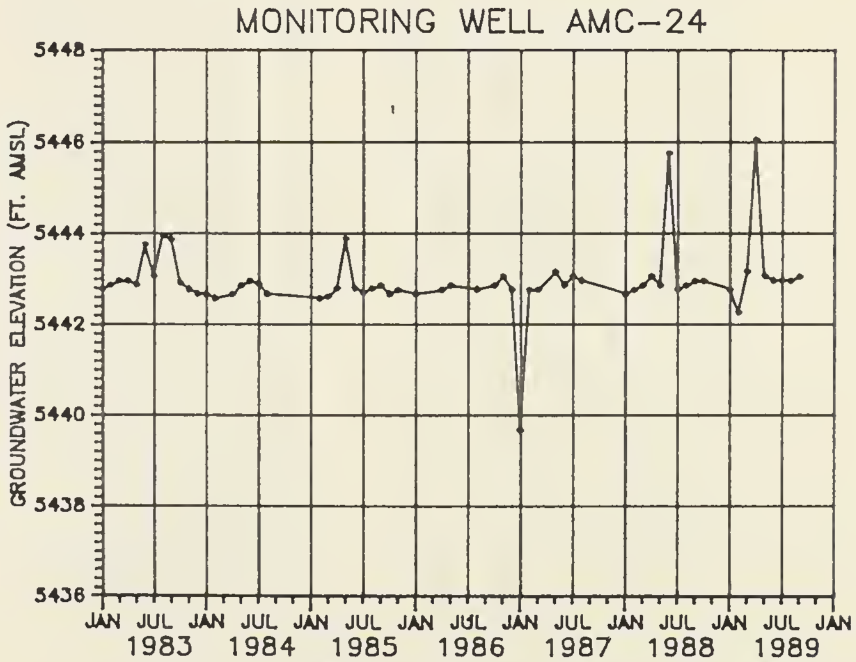
The magnitude of water level decline and rise with respect to the locations of these three monitoring wells suggest operations at the Weed Concentrator may impact the elevation of the alluvial groundwater system. At least one set of process ponds (the Barrel Ponds) are located immediately southeast of the Weed Concentrator (Figure 1-2). It is possible that groundwater recharge to the upper Metro Storm Drain area is realized through leakage from these ponds or other unstudied sources proximal to the Weed Concentrator complex.

The history of process activity at the Weed Concentrator also supports the contention that operational activity at the facility impacts water level elevations in the upper Metro Storm Drain area. Anaconda Minerals Company ceased operations at Weed Concentrator in early 1983. Montana Resources Inc. purchased and began operating the Weed Concentrator in 1986. The timing of these events relates directly to the time period during which water levels declined and rose in monitoring wells located in the upper Metro Storm Drain area. The fact that water levels have remained relatively stable in monitoring well AMC-24, located in the lower Metro Storm Drain area, suggests that the natural variability in groundwater elevations cannot explain the variability measured in wells located in the upper Metro Storm Drain area.

Water Level Trends in Selected Monitoring Wells (1983-1989)







Data Source: MBMG and Anaconda Minerals Company Files

Area I Operable Unit
Phase II Remedial Investigation
FIGURE 3-52

3.3.5 Aquifer Testing

Two types of aquifer tests were completed during the Phase II Remedial Investigation. These included slug tests and pumping tests. Slug tests were performed in several monitoring wells completed during the Phase I and Phase II Remedial Investigations to determine the spatial and vertical variability of hydraulic conductivity throughout the operable unit. Extended pumping tests were completed at four locations within the operable unit to determine aquifer parameters and to identify the absence or presence of boundary conditions.

3.3.5.1 Slug Tests

Although it is recognized that slug tests do not necessarily produce data which are quantitative with respect to aquifer hydraulics, the data are useful in evaluating gross characteristics in the Area I groundwater system both spatially and vertically. Table 3-5 summarizes results of slug tests completed at selected monitoring and pumping wells located within the operable unit. Figures 3-53 and 3-54 illustrate these data spatially for wells completed in the upper 10 feet of the alluvial groundwater system and for wells completed between 10 and 40 feet below the water table, respectively.

Examination of Figure 3-53 indicates that the portion of the shallow groundwater system directly adjacent to the Metro Storm Drain exhibits relatively low hydraulic conductivities. The hydraulic conductivity of the shallow system appears to increase with increasing distance from the Metro Storm Drain. Relatively high hydraulic conductivity values are also evident in the vicinity of the Butte Reduction Works tailings impoundments as compared to values calculated for wells completed both upgradient and cross-gradient of the area.

Hydraulic conductivity values obtained from wells completed in the interval from 10 feet to 40 feet below the water table (Figure 3-54) indicate relatively higher hydraulic conductivities in the area above Harrison Avenue as compared to areas below, or downgradient of Harrison Avenue. Hydraulic conductivities in this portion of the aquifer below Montana Street are relatively consistent.

TABLE 3-5

SUMMARY OF SLUG TEST DATA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Well No.[2]	Calculated Hydraulic Conductivity (Ft./Day)[1] Slug-In[3]	Slug-Out[4]	Average	Well Completion Depth[5]
GS-07	3.0			C
GS-08	5.0	6.5	5.8	C
GS-09	5.8	3.7	4.8	C
GS-10D	11.1	11.1	11.1	C
GS-10S	1.9	2.7	2.3	A
GS-11	8.6	4.4	6.5	A
GS-15D	28.2	17.6	22.9	B
GS-15S		37.9		A
GS-16		7.0		A
GS-17D	28.0	71.5	49.8	B
GS-17S	24.3	23.5	23.9	A
GS-18	28.3	12.8	20.6	A
GS-20	8.6	5.4	7.0	A
GS-21D	16.6	10.5	13.6	B
GS-21S	9.7	16.0	12.9	A
GS-22	7.6	3.2	5.4	A
GS-24D	16.6	11.8	14.2	B
GS-24S	2.4	0.7	1.6	A
GS-25	75.5	42.5	59.0	A
GS-26	40.6	10.3	25.5	A
GS-28		1.4		A
GS-29D	8.5	14.7	11.6	B
GS-29S	4.9	4.1	4.5	A
GS-30D	5.1	4.6	4.9	B
GS-30S	4.8	4.8	4.8	A
GS-31D	52.6	72.8	62.7	B
GS-31S	68.6	47.5	58.1	A
GS-32	3.6			B
GS-33	16.0			B
GS-34D	9.5	38.3	23.9	B
GS-34S	58.9	49.7	54.3	A
GS-35D	9.7	2.8	6.3	B

TABLE 3-5--continued

SUMMARY OF SLUG TEST DATA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Well No.[2]	Calculated Hydraulic Conductivity (Ft./Day)[1] Slug-In[3]	Slug-Out[4]	Average	Well Completion Depth[5]
GS-35S	8.7	60.2	34.5	A
GS-40	35.7	22.6	29.2	B
GS-41D	24.7	48.2	36.5	B
GS-41S	58.3	51.6	55.0	A
GS-42D	17.8	28.3	23.1	B
GS-42S	22.1	16.2	19.2	A
GS-43D	44.2	20.6	32.4	B
GS-43S	3.8	6.4	5.1	A
GS-44D	11.5	15.8	13.7	B
GS-44S	87.9	63.9	75.9	A
GS-45	20.1	7.2	13.7	B
GS-46S	65.0	10.0	37.5	A
PW-03		31.6		A
PW-04	12.4	9.8	11.1	A

NOTES:

(1) Calculated using method described in Bouwer and Rice (1976).

(2) Well locations shown on Exhibit I. Prefix to "GS" and "PW" wells (AI-GW) has been dropped. "S" indicates shallow and "D" indicates deeper well completion at same site.

(3) Test involved insertion of cylindrical apparatus into well and monitoring aquifer response.

(4) Test involved extraction of cylindrical apparatus from well following water level stabilization and monitoring aquifer response.

(5) A = Well completed in upper 10 feet of groundwater system.
B = Well completed 10 to 40 feet below water table.
C = Well completed greater than 40 feet below water table.

Blank indicates test was not completed, or data were not usable.

Map Showing Spatial Distribution of Hydraulic Conductivity Values
for Wells Completed in Upper 10 Feet of the Groundwater System;
Area I Operable Unit Phase II Remedial Investigation
FIGURE 3-53

Map Showing Spatial Distribution of Hydraulic Conductivity Values for Wells Completed 10 to 40 Feet Below Water Table; Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-54

In comparing hydraulic conductivity values in the upper 10 feet of the groundwater system to those in interval from 10 feet to 40 feet below the water table, slug test data indicate the following:

- In the upper portion of the operable unit, hydraulic conductivities appear to increase with depth in the area directly adjacent to the Metro Storm Drain and decrease with depth in areas distal to the drain.

- In the lower portion of the operable unit, hydraulic conductivities appear to increase with depth in the vicinity of the Butte Reduction Works tailings impoundments and decrease with depth west of the impoundments.

3.3.5.2 Pumping Tests

Field forms resulting from completion of pumping tests in the Area I Operable Unit are contained in Appendix B-6. Table 3-6 summarizes results of pumping tests completed during the Phase II Remedial Investigation at the Area I Operable Unit. In general, pumping test data indicate the following:

- The shallow alluvial system in the upper Metro Storm Drain area exhibits relatively low transmissivities as compared to the shallow groundwater systems elsewhere in the operable unit.

- The alluvial system in the vicinity of the Butte Reduction Works tailings impoundments exhibits the highest transmissivity of all areas investigated within Area I during the Phase I and Phase II Remedial Investigations.

- The alluvial groundwater system beneath the Colorado Tailings exhibits relatively low transmissivities which are similar to that measured in the central Metro Storm Drain area between Montana Street and Harrison Avenue.

- The shallow alluvial groundwater system is highly anisotropic and heterogeneous throughout the operable unit. Discussion of individual pumping tests completed during the Phase II Remedial Investigation is presented in the following sections.

TABLE 3-6

SUMMARY OF PUMPING TEST DATA;
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Pumping Well	Duration of Test (Minutes)	Type of Test	Observation Well	Perf. Interval (Feet below Ground Surface)	Method of Analysis[1]	Transmissivity (Ft^2/Day)	Aquifer[2] Thickness (Ft)	Hydraulic Conductivity (Ft/Day)	Storage Coefficient
AI-PW-01	922	Constant Discharge		17 - 42					
		Observation Well Drawdown	PW-01		2	50	20	2.5	N/A
AI-PW-02	1440	Constant Discharge		0 - 25					
		Observation Well Drawdown	OB-1N	10 - 15	1	390	25	16	0.16
			OB-2N	10 - 15	1	820	25	32	0.0001
			OB-1E	10 - 15	1	350	25	14	0.08
			OB-2E	10 - 15	1	110	25	4.4	0.002
AI-PW-03	1440	Constant Discharge		9 - 39					
		Observation Well Drawdown	OB-1S	9.5 - 14.5	1	6000	35	170	0.33
			OB-2S	9.8 - 14.8	1	2500	35	71	0.05
			GS-16	11.2 - 16.2	1	4500	35	130	0.006
			OB-1E	9.2 - 14.2	1	6000	35	170	0.08
		Observation Well Recovery	OB-1S	9.5 - 14.5	1	4900	35	140	0.41
			OB-2S	9.8 - 14.8	1	3000	35	85	0.04
			GS-16	11.2 - 16.2	1	5100	35	140	0.008
			OB-2E	10.7 - 15.7	1	2400	35	70	0.07
AI-PW-04	770	Constant Drawdown		9.5 - 19.5					
		Observation Well Drawdown	CT-84-9	15.9 - 20.9	1	270	19.5	15	0.0002
			OB-1N	10 - 15	1	460	19.5	24	0.0004
			OB-1E	8.8 - 13.8	1	380	19.5	20	0.05

[1] Method of Analysis:

1) Neuman, 1975, Analysis of Pumping Test Data From Anisotropic Unconfined Aquifers Considering Delayed Gravity Response, Water Resources Research, Vol. II, No. 2, p. 329.

2) Driscoll, 1986, Groundwater and Wells, Johnson Division, St. Paul, Minnesota, Method of Estimating Transmissivity with Specific Capacity Data, p. 1021.

[2] Based on Lithologic Logs.

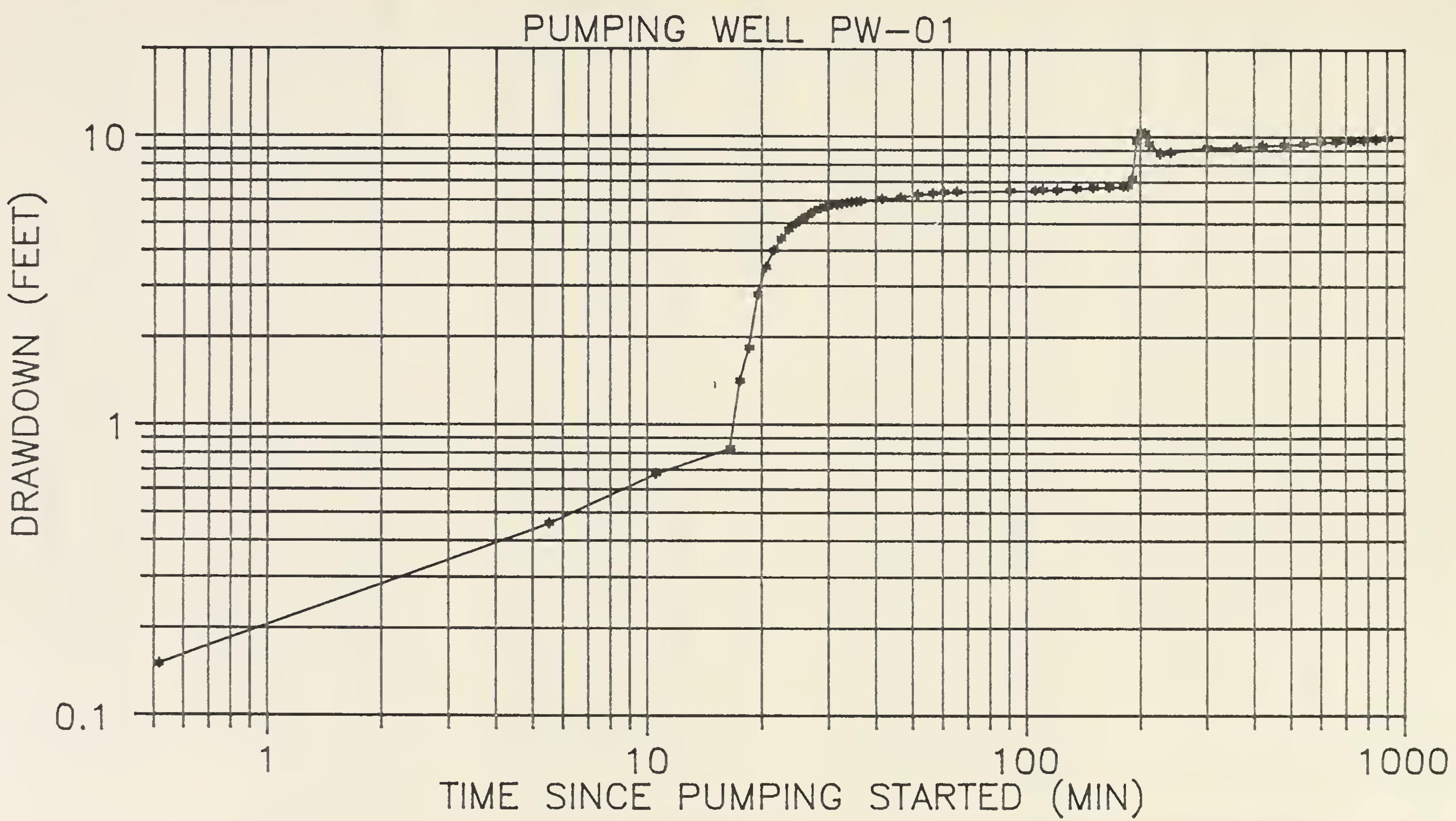
Pumping Well AI-PW-01

Material encountered while drilling monitoring wells and pumping well AI-PW-01 in the upper portion of the operable unit near the Butte-Silver Bow County shop complex consisted primarily of thick zones of silt and clay with relatively thin interbeds of sand and gravel. Pumping well AI-PW-01 (Exhibit I) was completed at a depth of 42 feet below ground surface immediately adjacent to monitoring wells AI-GW-GS-07, AI-GW-GS-10D and AI-GW-GS-10S (Figure 3-4).

Split-spoon samples collected while drilling pumping well AI-PW-01 encountered several sand and gravel beds ranging in thickness from one inch to five inches. These thin coarse-grained zones appear to be the primary water bearing units in the shallow alluvial system in the upper Metro Storm Drain area.

A constant discharge test was conducted in well AI-PW-01 for 15.4 hours at a discharge rate of 2.3 gallons per minute (gpm). A maximum drawdown of 9.83 feet resulted in the pumping well. Figure 3-55 is a logarithmic plot of time/drawdown data collected from pumping well AI-PW-01. Time/drawdown data for observation wells GS-07, GS-10S, and GS-10D are not presented because measurable water level changes did not occur in these wells throughout the pumping test. Based on the volume of water standing in the well casing prior to pumping (38.5 gallons) and a discharge rate of 2.3 gpm, the first 17 minutes of the test consisted of dewatering the casing. The effect of casing storage is represented by the straight line portion of the curve shown on Figure 3-55. Near steady state conditions were reached approximately 30 minutes into the test. The dramatic water level change recorded approximately 200 minutes into the test is a result of an increase in the discharge rate.

Because measurable water level changes did not occur in nearby observation wells and the time/drawdown curve for pumping well AI-PW-01 was characteristic of relatively low permeability conditions, curve matching techniques were not used to analyze pumping data. Instead, an estimate of transmissivity was calculated using a specific capacity method of estimating transmissivity (Driscoll, 1986). Based on a specific capacity of 0.25 gpm/ft, the resulting transmissivity is approximately 50 ft^2/day. Using an aquifer thickness of 20 feet results in a hydraulic conductivity of 2.5 ft/day. These values are in relatively close



Pumping Well:	AI-PW-01
Distance from Pumping Well (ft):	
Saturated Thickness (ft):	19.0
Perforated Interval (feet below ground surface)	
Pumping Well:	17 to 42
Observation Well:	
Test Duration (minutes):	900
Method of Analysis:	Specific Capacity (Driscoll, 1986)

Plot of Time/Drawdown Data at
Pumping Well AI-PW-01
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-55

agreement with those calculated from pumping test data collected during a the Phase I Remedial Investigation at well AI-GW-GS-07 (MultiTech, 1987).

The lack of response in wells AI-GW-GS-07 and AI-GW-GS-10D indicates the vertical hydraulic conductivity in the area is extremely low and/or the zones of completion are not well connected. Because observation well AI-GW-GS-10S (with a screened interval depth similar to well AI-PW-01) did not respond during the test, it is apparent low permeability sediments are present in this portion of the operable unit.

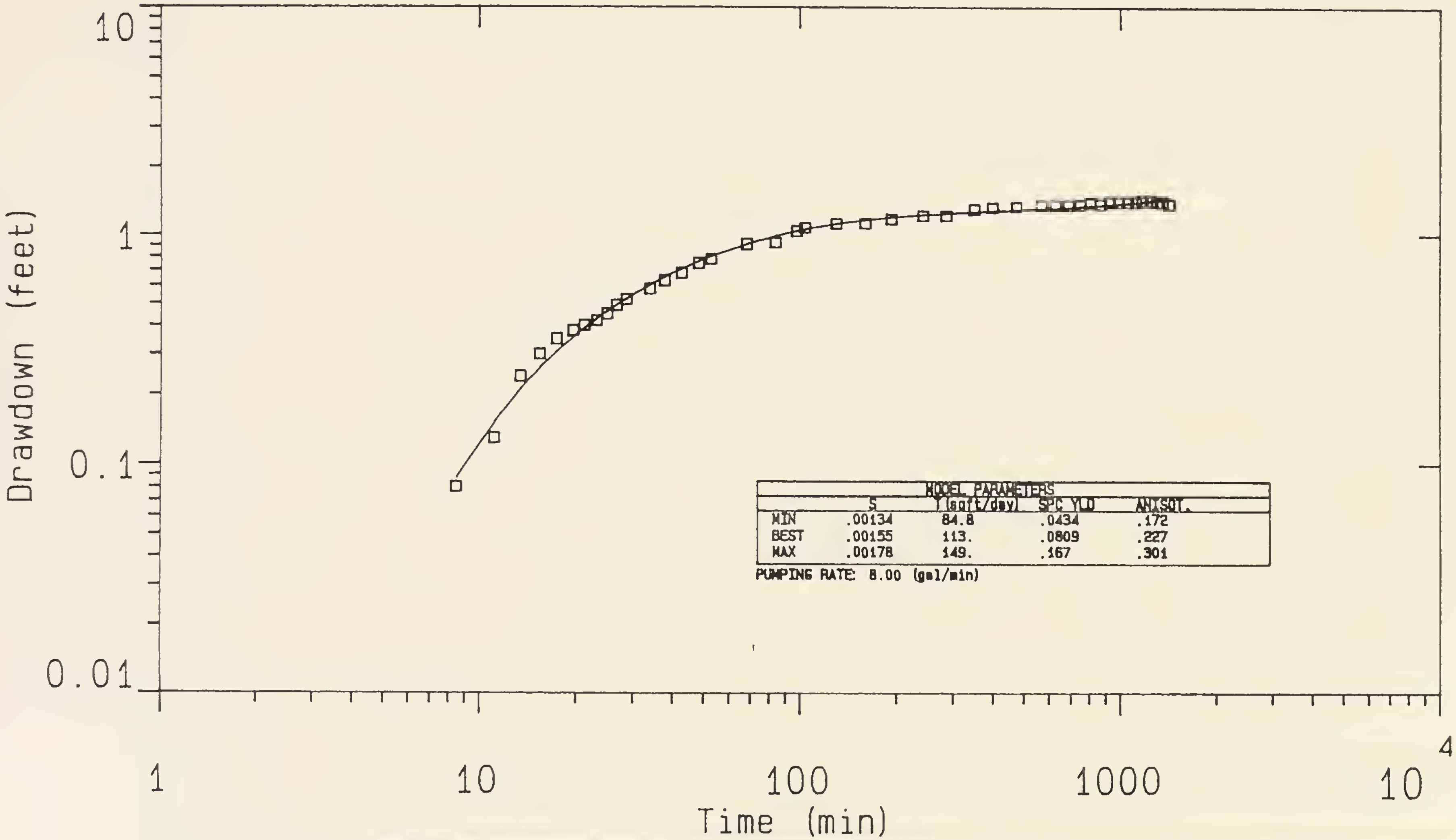
Transmissivity values resulting from analyses of data from pumping well AI-PW-01 and from well AI-GW-GS-07 during the Phase I Remedial Investigation (MultiTech, 1987) indicate the permeability of the unconsolidated material in the vicinity of the upper Metro Storm Drain area is low and consistent to at least 160 feet below ground surface. The pumping test conducted in well AI-GW-GS-07 during the Phase I Remedial Investigation resulted in a calculated transmissivity of approximately 40 ft^2/day (MultiTech, 1987).

Pumping Well AI-PW-02

A 24 hour constant discharge test was conducted in well AI-PW-02 located in the central Metro Storm Drain area (Exhibit I). Water levels were measured in six observation and monitoring wells adjacent to well AI-PW-02 and in the pumping well. Time/drawdown curves developed from water level data collected from four of the observation wells indicate transmissivities in the vicinity of well AI-PW-02 range from 110 ft^2/day to 820 ft^2/day (Table 3-6).

Figures 3-56 and 3-57 are time/drawdown curves developed with water level data measured in observation wells 02-OB-2E and 02-OB-1E, respectively. The data were analyzed using a software package that statistically matches type curves to the field data using the Neuman (1975) method for partially penetrating wells in an unconfined aquifer. Additional plots with associated model curves are contained in Appendix B-6.

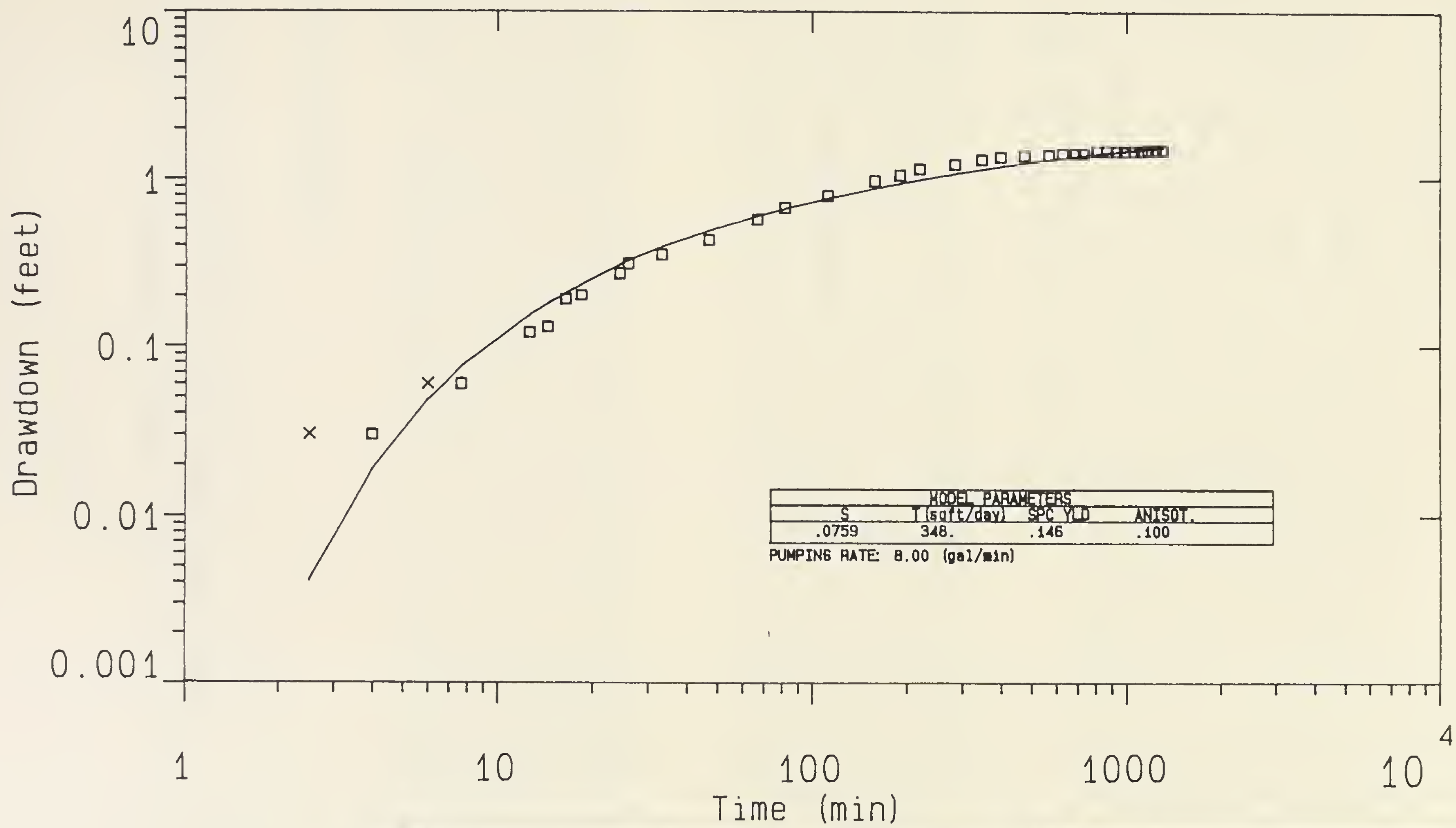
Transmissivities calculated with data derived from wells located east of the pumping well (parallel to the Metro Storm Drain) were lower than transmissivities calculated with data obtained from wells located north of the pumping well (normal to the Metro Storm Drain).



Pumping Well:	AI-PW-02
Distance from Pumping Well (ft):	52.7
Saturated Thickness (ft):	25
Perforated Interval (feet below ground surface)	
Pumping Well:	0 to 25
Observation Well:	10 to 15
Test Duration (minutes):	1440
Method of Analysis:	Neuman, 1975

Plot of Time/Drawdown Data at Observation Well 02-OB-2E
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-56



Pumping Well:	AI-PW-02
Distance from Pumping Well (ft):	9.9
Saturated Thickness (ft):	25
Perforated Interval (feet below ground surface)	
Pumping Well:	0 to 25
Observation Well:	10 to 15
Test Duration (minutes):	1440
Method of Analysis:	Neuman, 1975

Plot of Time/Drawdown Data at Observation Well 02-OB-1E
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-57

This phenomenon is likely attributable to the horizontal anisotropic nature of the fluvially deposited sediments. Storage coefficient values calculated from the time/drawdown curves ranged from 0.0001 to 0.16.

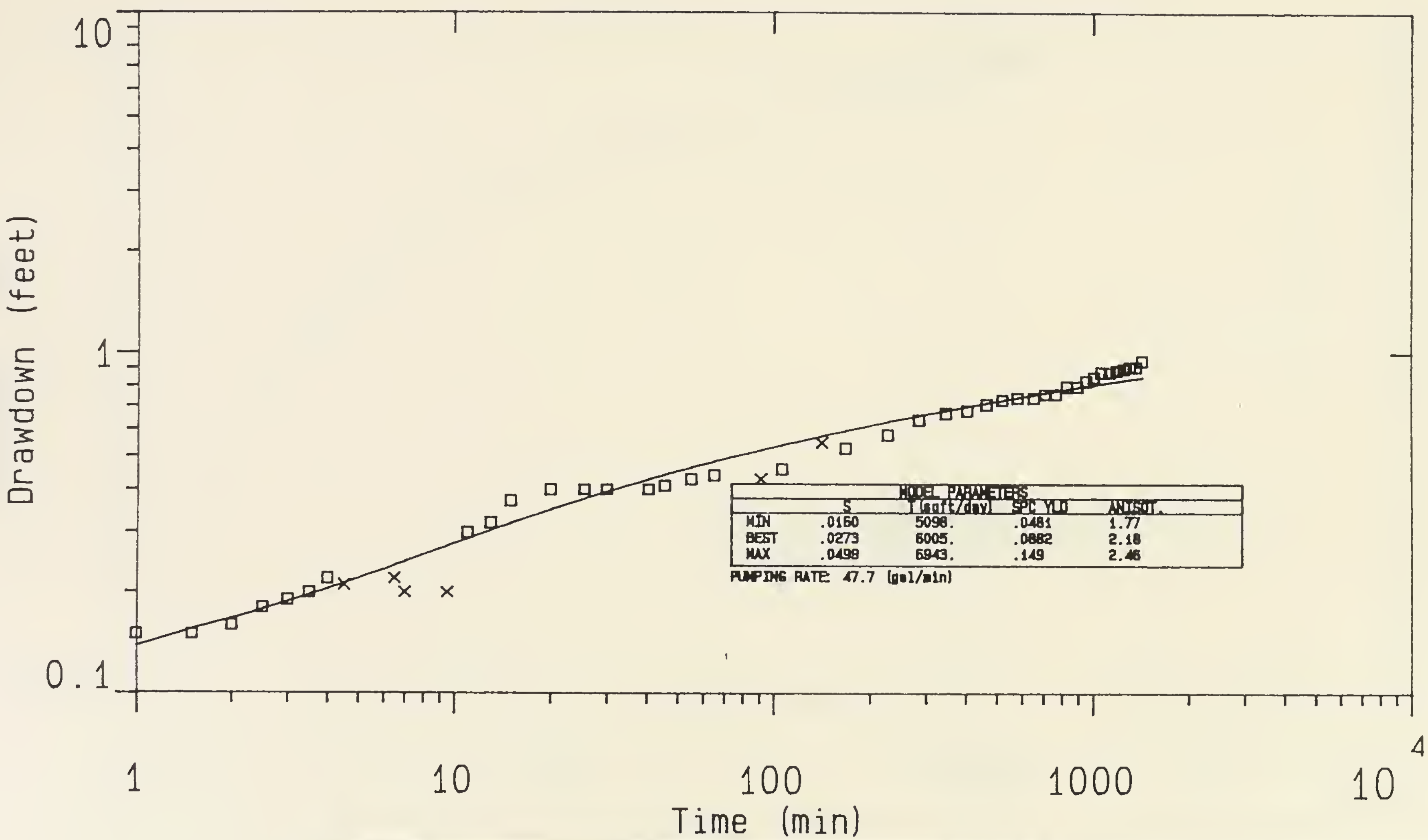
Water levels measured in observation well AI-GW-GS-30S, located across the storm drain from pumping well AI-PW-02, dropped measurably during the pumping test (0.07 feet). This indicates water flowing in the storm drain through this reach does not act as a constant head source of water to deeper zones of the shallow aquifer. It is evident from water levels measured in monitoring well AI-GW-GS-30S that the cone of depression induced from pumping well AI-PW-02 extended beneath the Metro Storm Drain. This fact also suggests there is significant vertical versus horizontal anisotropic conditions in the area. Boundary conditions were not apparent at the end of the 24 hour test as drawdown in the monitored wells continued to termination of pumping.

Transmissivity values calculated from the pumping test at well AI-PW-02 during the Phase II Remedial Investigation were higher than transmissivity values calculated from pumping tests completed in nearby and deeper wells AI-GW-GS-08 and AI-GW-GS-09 during the Phase I Remedial Investigation (MultiTech, 1987). Well AI-PW-02 is screened from 0 to 25 feet below ground surface; well AI-GW-GS-09 is screened from 60 to 75 feet below ground surface; and well AI-GW-GS-08 is screened from 128 to 146 feet below ground surface.

Transmissivity values calculated from wells AI-PW-02, AI-GW-GS-09 and AI-GW-GS-08 were approximately 400 ft^2/day, 60 ft^2/day, and 45 ft^2/day, respectively. These data indicate the transmissivity of the alluvial system in the central storm drain area decreases with depth. These data also support the concept that the measured upward groundwater gradient in this portion of the operable unit (see Section 3.3.4) may be created by a decrease in permeability in the deeper sediments to the southwest, along the Metro Storm Drain.

Pumping Well AI-PW-03

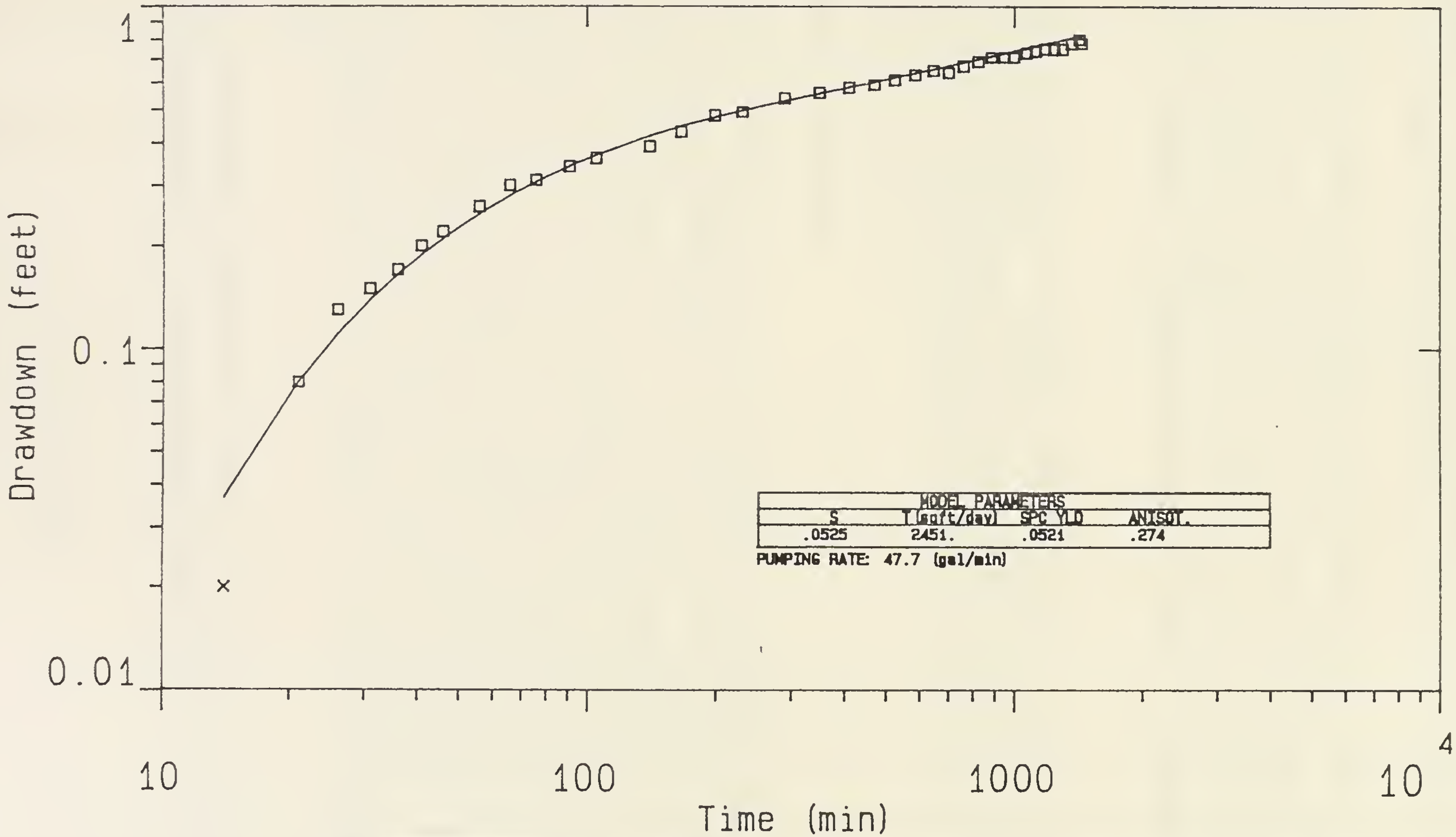
A 24-hour constant discharge test was conducted in well AI-PW-03 located in the north cell of the Butte Reduction Works tailings impoundment (Exhibit I). Water levels were measured in five observation wells during the pumping test. Figures 3-58 and 3-59 are plots



Pumping Well:	AI-PW-03
Distance from Pumping Well (ft):	9.7
Saturated Thickness (ft):	35
Perforated Interval (feet below ground surface)	
Pumping Well:	9 to 39
Observation Well:	9.2 to 14.2
Test Duration (minutes):	1440
Method of Analysis:	Neuman, 1975

Plot of Time/Drawdown Data at Observation Well 03-OB-1E
Area I Opeable Unit Phase II Remedial Investigation

FIGURE 3-58



Pumping Well:	AI-PW-03
Distance from Pumping Well (ft):	51.2
Saturated Thickness (ft):	35
Perforated Interval (feet below ground surface)	
Pumping Well:	9 to 39
Observation Well:	9.8 to 14.8
Test Duration (minutes):	1440
Method of Analysis:	Neuman, 1975

Plot of Time/Drawdown Data at Observation Well 03-OB-2S
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-59

of time/drawdown data for observation wells 03-OB-1E and 03-OB-2S, respectively. Additional time/drawdown plots with their associated modeled curves are presented in Appendix B-6. Transmissivity values calculated from time/drawdown data and recovery data from four of the observation wells ranged from 2400 ft^2/day to 6000 ft^2/day (Table 3-6).

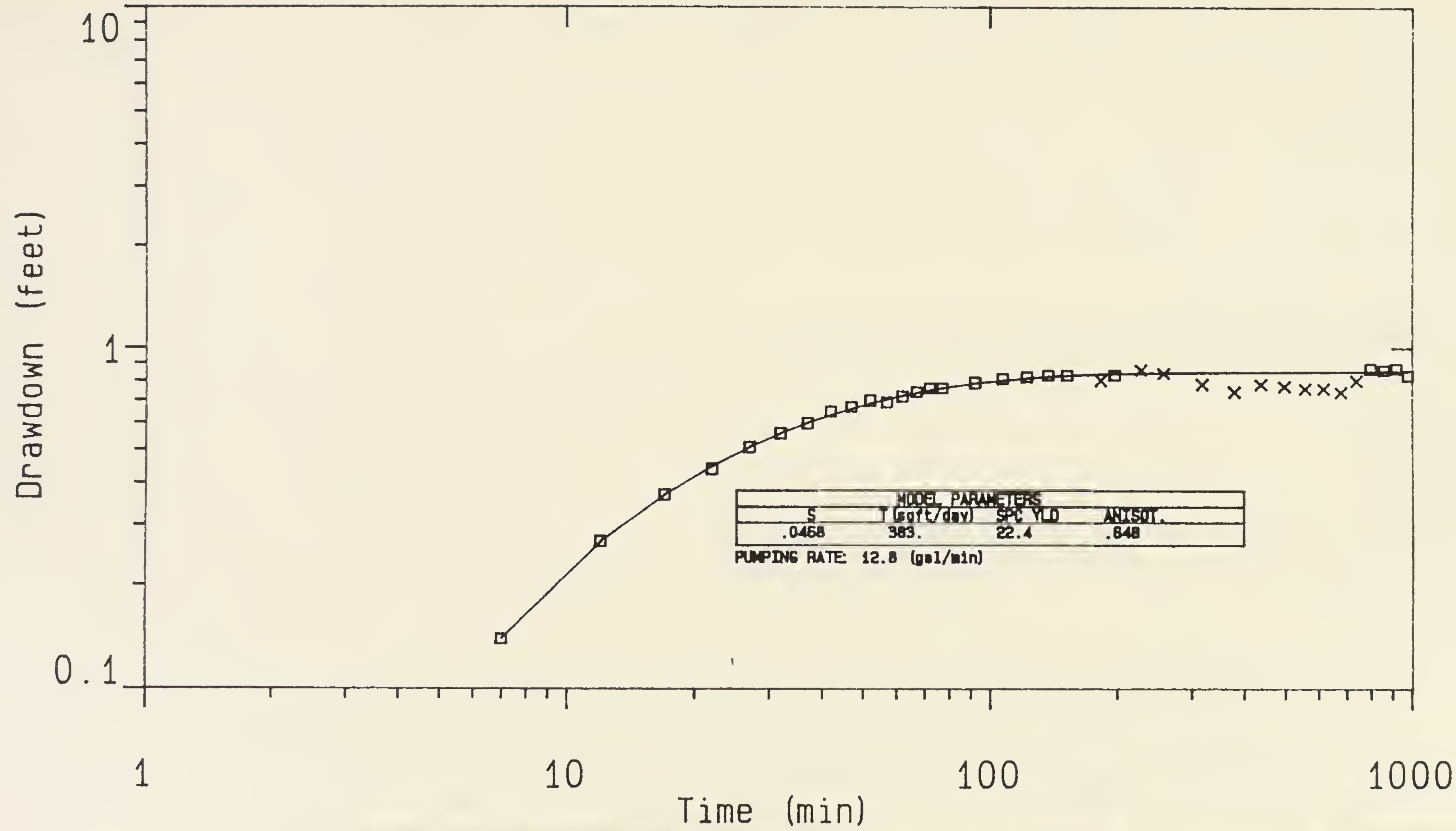
These values constitute the highest measured transmissivities in the shallow groundwater system within the Area I Operable Unit. Storage coefficient values calculated from the time/drawdown plots from this test ranged from 0.005 to 0.34 (Table 3-6). Anisotropy values calculated from the time/drawdown plots ranged from 0.06 to 0.4 (vertical/horizontal hydraulic conductivity). No apparent boundary conditions were encountered throughout the test.

As previously discussed, the lithology of the alluvial system underlying the Butte Reduction Works tailings impoundments area is predominantly composed of coarse, moderately well sorted sand. These highly permeable sand deposits are likely associated with sediments derived from Missoula Gulch.

Pumping Well AI-PW-04

A constant discharge pumping test was conducted in well AI-PW-04, located near the center of the Colorado Tailings (Exhibit I). Water levels were measured in five observation wells throughout the duration of the test. Well AI-PW-04 was pumped at an average rate of 12.8 gpm for 16.5 hours resulting in a maximum drawdown of 8.63 feet in the pumping well at the termination of the test. Figures 3-60 and 3-61 are time/drawdown plots constructed with water level data measured in observation wells 04-OB-1E and 04-OB-1N, respectively. Additional time/drawdown plots with associated modeled curves are contained in Appendix B-6. Transmissivity values calculated from time/drawdown data from three of the observation wells range from 270 ft^2/day to 380 ft^2/day (Table 3-6). Storage coefficient values range from 0.0002 to 0.05, indicating the sand and gravel aquifer may be partially confined.

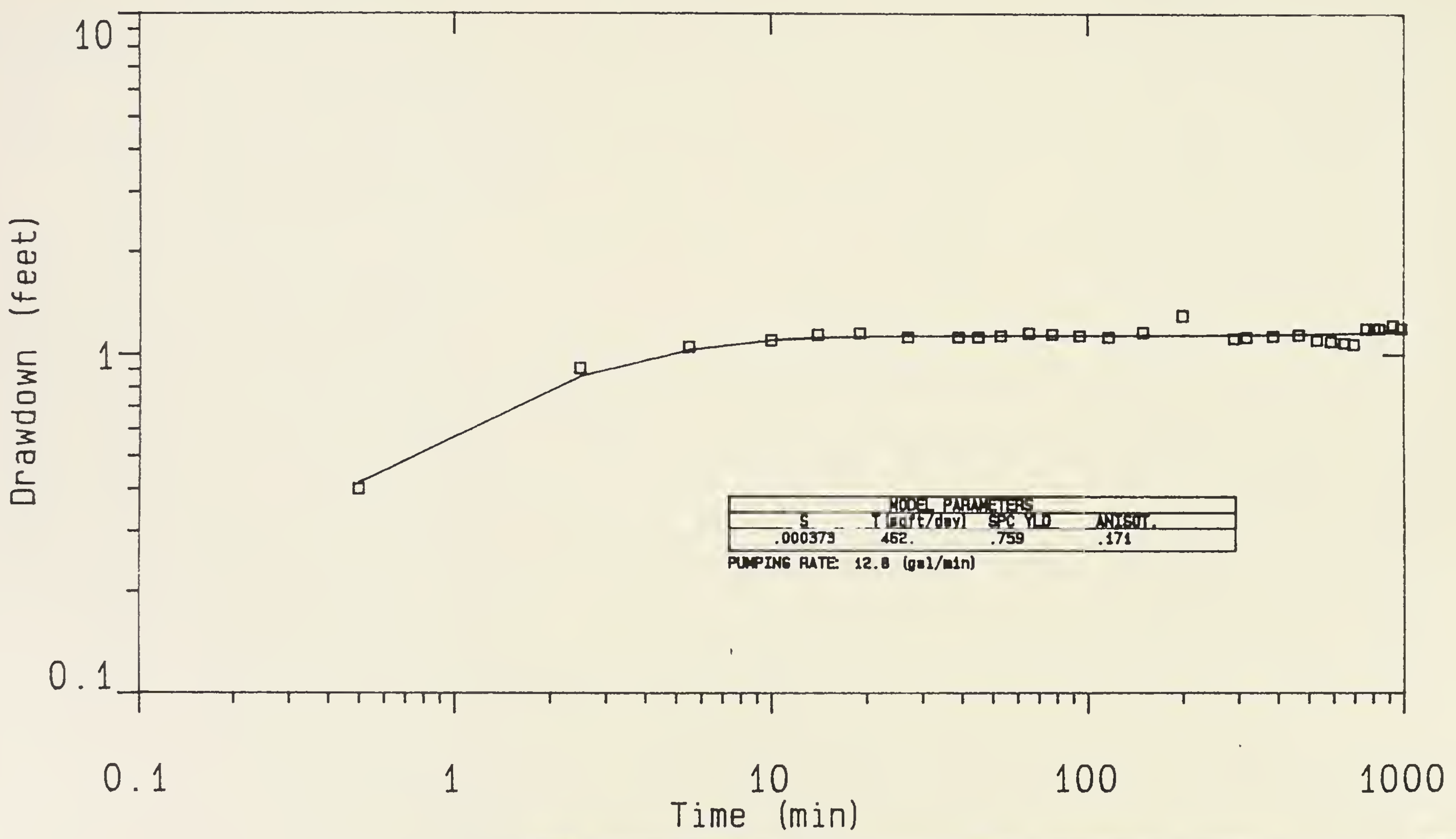
No apparent boundary conditions were encountered during the 16.5 hours of pumping. The test was terminated due to fluctuating pumping rates which resulted in erratic water levels.



Pumping Well:	AI-PW-04
Distance from Pumping Well (ft):	
Saturated Thickness (ft):	10.7
Perforated Interval <u>(feet below ground surface)</u>	
Pumping Well:	9.5 to 19.5
Observation Well:	8.8 to 13.8
Test Duration (minutes):	990
Method of Analysis:	Neuman, 1975

Plot of Time/Drawdown Data at Observation Well 04–OB–1E
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-60



Pumping Well:	AI-PW-04
Distance from Pumping Well (ft):	8.4
Saturated Thickness (ft):	19.5
Perforated Interval (feet below ground surface)	
Pumping Well:	9.5 to 19.5
Observation Well:	10 to 15
Test Duration (minutes):	990
Method of Analysis:	Neuman, 1975

Plot of Time/Drawdown Data at Observation Well 04–OB–1N
Area I Operable Unit Phase II Remedial Investigation

FIGURE 3-61

Pumping well AI-PW-04 is screened from 9.5 feet to 19.5 feet below ground surface. Observation wells 04-OB-1E and 04-OB-1N (Figure 2-4) are screened from 8.8 to 13.8 feet below ground surface and 10 to 15 feet below ground surface, respectively. Observation well CT-84-9 (Figure 3-4) is screened from 15.9 to 20.9 feet below ground surface. The slightly lower transmissivity value calculated with water level data measured in observation well CT-84-9 (Table 3-6) indicates the permeability of the unconsolidated material underlying the Colorado Tailings may decrease slightly with depth. However, the relatively close grouping of calculated transmissivity values from the three observation wells located in three different directions from the pumping well indicate anisotropic conditions in the shallow groundwater system at the Colorado Tailings are minimal.

SECTION 4.0 TAILINGS/CONTAMINATED SOILS INVESTIGATION

PULL-OUT LEGEND TO AID
READING OF SECTION 4.0

EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore
		Transported Fill
6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic
		Native Soils/Sediment
8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

4.0 TAILINGS/CONTAMINATED SOILS INVESTIGATION

The tailings/contaminated soils investigation completed during the Area I Phase II Remedial Investigation was performed in two separate but interrelated phases. One component of the investigation evaluated impounded tailing deposits within the study area. This included characterization of the historic Parrott Tailings deposit near the upper end of the Metro Storm Drain, the historic Butte Reduction Works tailing impoundments located west of Montana Street, and the Colorado Tailings, located near the western end of the study area (Figure 1-2). The second element of the tailings/contaminated soils investigation characterized soils and dispersed tailing deposits at sites within the study area located between and adjacent to the impounded deposits.

Although the dispersed tailings and impounded tailings investigations were conducted separately, in many locations the lateral extent of tailings impoundments was obscured by recent fill material. For this reason, it became evident that a common analysis of site soils and mine wastes incorporating data derived through both components of the contaminated soils and tailings investigation was appropriate for the site. Methods used to collect data during the impounded tailings and dispersed tailings components of the investigation are therefore presented separately in the following sections; the section of this report which presents and summarizes collected data unites the two components into one discussion.

The purpose of the contaminated soils/tailings investigation was to provide data for use in completing the site public health and environmental assessment and for use in evaluating various remedial alternatives during the forthcoming site feasibility study. In addition, data were collected to evaluate the impact of contaminated soils/tailings on receiving surface water and groundwater systems and on air quality. Efforts were also made to estimate volumes of impounded tailing deposits and selected material units to provide a basis from which removal alternatives can be evaluated during the site feasibility study.

4.1 METHODS

Three general work tasks were completed during the contaminated soils/tailings investigation in the Area I Operable Unit. These included a surface soils/waste material mapping task which identified various soil and waste types within the study area, a dispersed

tailings sampling task, and an impounded tailings sampling task. X-ray fluorescence spectrometer (XRF) analyses were completed on most samples collected during both the dispersed tailings and impounded tailings work tasks. The methodology and application of the XRF to this investigation is discussed separately within this section of the report.

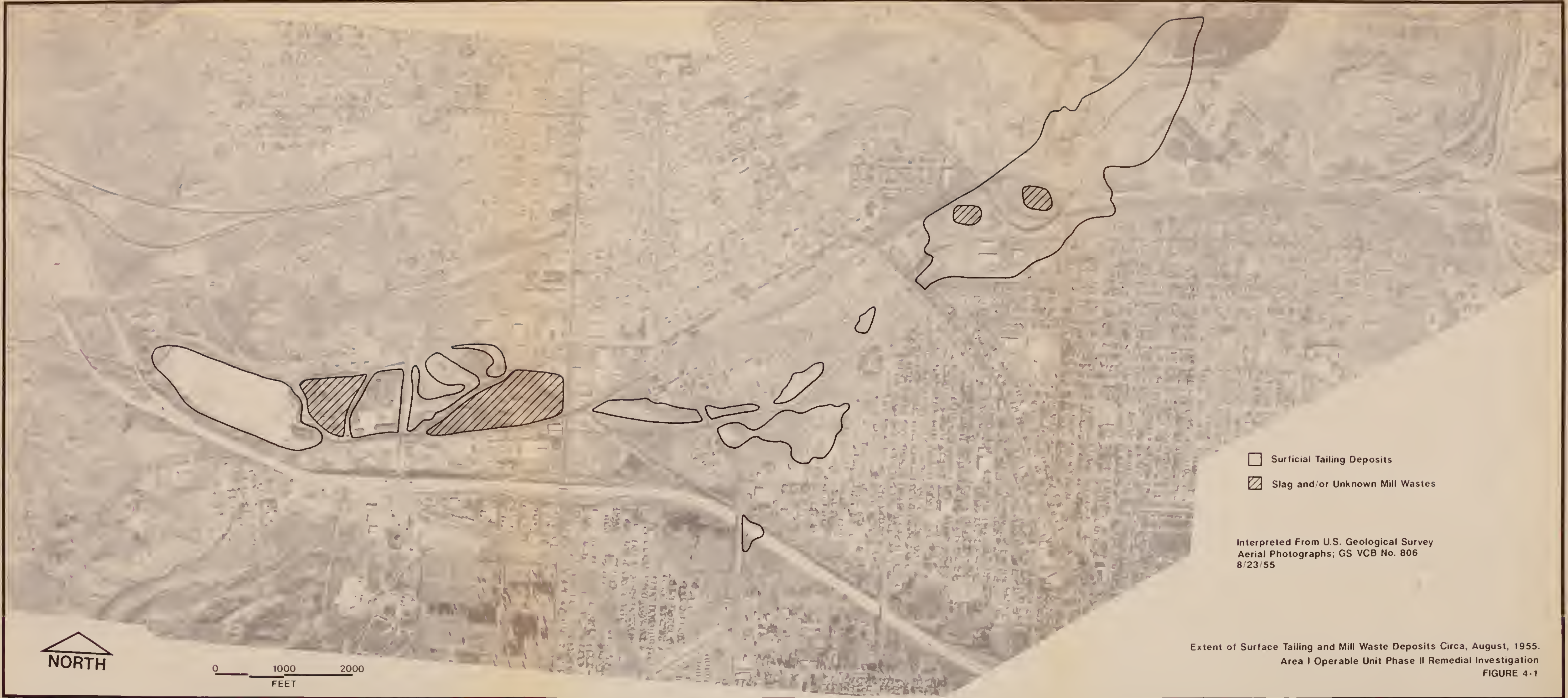
4.1.1 Soils/Waste Material Mapping

Field mapping was completed utilizing 1 inch = 200 feet aerial photo base maps. EPA 1983 color aerial photographs and USGS 1955 black and white aerial photographs were used to aide in interpreting site conditions. A soils/waste material type description system was developed to catalog soils and waste material types present within the study area. The classification system developed was based on waste material type, depth to mine waste, mine waste thickness and cover material type. Natural soils were classified by degree of disturbance and drainage characteristics.

Mine wastes within the study area were identified in the field through evaluation of color, texture, and stratification. Mine wastes typically exhibited high chroma colors resulting from the abundance of iron oxides, sandy to silty soil textures, low organic carbon levels, and were distinctly stratified. The 1955 aerial photographs were useful in locating exposed mine waste deposits that have subsequently been covered or removed. Figure 4-1 illustrates the extent of exposed mine waste deposits within and adjacent to Area I as interpreted from the 1955 aerial photographs.

Field mapping was completed by making numerous transects across the study area on foot and occasionally digging soil profile observation pits with shovels and hand augering equipment. Soil pit depths used in preparing the soils/waste material map ranged from several inches to six feet. Descriptions of soil profiles at each location were recorded in a field book and soil pit locations were marked on a field map. Naturally exposed cuts were utilized to locate mine wastes occurring at depths greater than six feet. After completing several transects through the study area, soils/waste material unit boundaries were delineated on a 1:200 field map.

Following the initial field mapping exercise, a draft soils map was prepared. Map unit acreage was calculated with a polar planimeter; soils/waste material unit descriptions were



Extent of Surface Tailing and Mill Waste Deposits Circa, August, 1955.
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-1

prepared and incorporated into a legend to the map. The initial survey identified five major mapping units with 30 subunits in the study area. The second phase of the soils/waste material mapping exercise included additional field mapping to fill data gaps discovered through review of the initial site map. This effort generally refined map unit boundaries and verified questionable parcels within the study area. Supporting information used in preparing the soils/waste map is contained in Appendix C-1. Addition site data collected during dispersed tailings and impounded tailings investigations were also utilized to refine the site map.

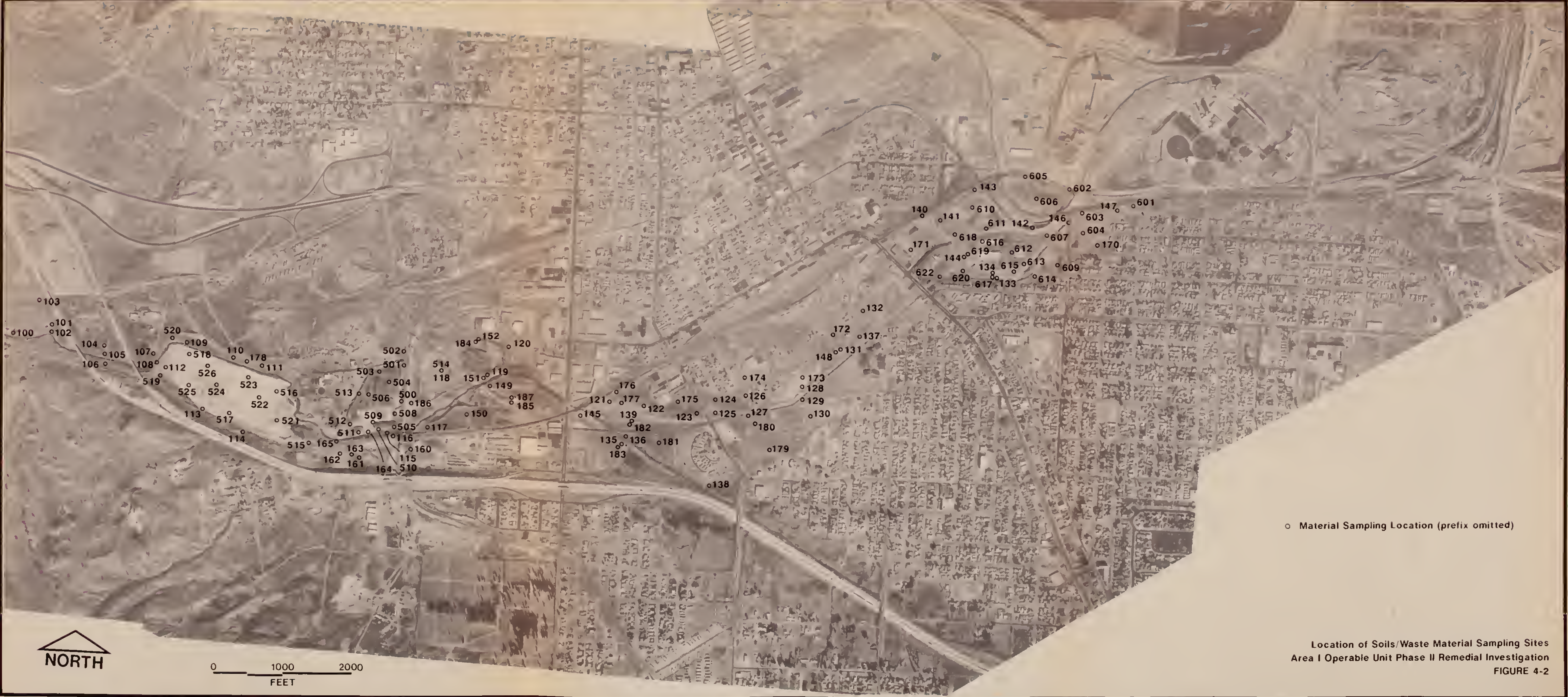
The final soils/waste material map was prepared on a 1 inch = 500 feet photobase map. A map of this scale was better suited for presentation in a report and adequately presented major map units which reflected general soil, cover, and mine waste materials in the study area.

4.1.2 Dispersed Tailings Sampling

The dispersed tailings investigation consisted primarily of soils/waste material sample collection, sample description, laboratory analyses of selected samples, and XRF analyses of collected samples. Sites from which soil samples were collected during the dispersed tailings investigation are shown on Figure 4-2. Location information for dispersed tailings sample sites are contained in Appendix C-2.

As described previously, the dispersed tailings sampling effort focused on areas within Area I which were not investigated during the impounded tailings investigation. These areas included parcels within the study area exclusive of the Parrott Tailings, the Butte Reduction Works tailings impoundments, and the Colorado Tailings. Sample sites were located such that sampled material would be representative of map units identified during the soils/waste material mapping task. In addition, certain sites were selected to provide adequate spatial coverage of the study area.

Initial sampling sites were selected following review of historic maps and photos and current aerial photographs and in consideration of constraining conditions (pavement, known coarse fill areas, and buried utilities). As sampling proceeded, several of the planned sites were abandoned due primarily to the difficulty of hand augering through mixed cover/fill



Location of Soils/Waste Material Sampling Sites

Area I Operable Unit Phase II Remedial Investigation

FIGURE 4-2

material. Alternative methods of collecting samples were used at these sites as described later in this section.

A surface sample (0-1 or 0-2 inches) was obtained from every sample site using a hand trowel. Subsurface samples were collected at selected sites using a stainless steel soil auger and were separated according to texture, color, consistency, and presence of organic matter. A total of 71 surface samples and 160 subsurface samples were collected from 71 locations during the dispersed tailings sampling effort during the Phase II Remedial Investigation in Area I. Boring logs for dispersed tailings sample sites are numbered from 100 to 187 and are contained in Appendix C-3.

Where holes were hand augered through fairly consistent material and the hole remained open, sampling proceeded to what was believed to be the original soil surface, until several feet of the same material was encountered, or until auger refusal was realized. Holes which tended to close due to the presence of heaving sands or plastic silts and clays were initially augered with a 6-inch auger to two to four feet below ground surface and cased with 5-inch PVC. A 4-inch auger was then inserted into the cased hole and the borehole was advanced to approximately six feet below ground surface. This portion of the borehole was cased with decontaminated 4-inch PVC. The total depth of the borehole was then achieved utilizing a 2-inch auger.

Soil samples were extracted from inside of each auger bucket after all potentially contaminated material was removed from the bucket exterior and from the top of the bucket. When more than one bucket of material was removed for a single sample, the entire mass of material was thoroughly mixed by rolling on a decontaminated neoprene pad. A subsample from this composite sample was then collected for analysis.

Certain areas within the study area were not conducive to hand augering sampling methods. In these instances, a backhoe was used to access the subsurface. The backhoe excavated a soil pit from which soil profile descriptions were made and samples were collected. Samples obtained using the backhoe were carefully separated upon retrieval. Composites of deep profiles of loose landfill material were made by sampling several locations of several cubic yards of the excavated debris. Samples of deeper, more consistent material were taken from

the bucket interior. Depths to each horizon were measured from the edge of the excavated hole.

All sampling equipment used during the dispersed tailings sampling effort was decontaminated before collection of each sample. The decontamination procedure involved first washing the equipment with water and brushes. If necessary, liquinox was used to remove sticky soil material. This was followed by a nitric acid rinse and a final deionized water rinse.

Each collected sample was placed in a plastic ziploc bag and assigned a sample number. Necessary paperwork was filled out in the field to document sample number, sample location, sample date, chain-of-custody, and other pertinent information. Sample bags were placed in locked coolers in the field and transported to a designated sample staging area. Upon arrival at the sample staging area, the samples were placed in numerical order into a locking steel storage cabinet.

Portions of collected samples were analyzed using an X-ray fluorescence spectrometer (XRF) in accordance with procedures described in Section 4.1.4 to assist in selecting samples for laboratory analysis and to identify data gaps. A second, less intensive soil sampling effort was conducted to fill data gaps identified through review of initial data. Selected samples were shipped to either a CLP laboratory or a private laboratory for analysis of parameters listed in Table 4-1.

Sampling for organic compounds in soils was completed in a limited fashion proximal to Silver Bow Creek, north of the Montana Pole Superfund site. This sampling effort was performed to determine if any off-site migration of organic contaminants had occurred at the Montana Pole site. Sampling for organic compounds was completed using soil augering procedures described previously.

4.1.3 Impounded Tailings Sampling

The field investigation associated with the study of impounded tailings sites in Area I consisted primarily of a drilling and sampling program supplemented, where appropriate, by hand soil augering sampling techniques. Sample site locations were determined in

TABLE 4-1

LABORATORY ANALYSES LIST FOR SOILS AND TAILINGS SAMPLES COLLECTED DURING THE AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Total Metals, Water Soluble Metals and Metals by Grain Size[a]	
Aluminum	Organics[a]
Antimony	Routine Analytical Services (RAS) list
Arsenic	
Barium	
Beryllium	
Cadmium	
Calcium	
Chromium	EP Toxicity[a]
Hexavalent Chrome[a]	
Cobalt	
Copper	Grain Size[a]
Iron	
Lead	
Magnesium	X-Ray Diffraction Speciation[a]
Manganese	
Mercury	
Nickel	Acid-Base Account[a]
Potassium	
Selenium	
Silver	pH/SC[a]
Sodium	
Thallium	
Vanadium	Bulk Density[a]
Zinc	

[a] Selected samples only

consideration of lateral spacing through the impounded sites and in response to evaluations of surface geophysical investigations described in Section 3.3.1. Historic aerial photographs of Butte were also utilized in evaluating mine waste distribution and occurrence. Underground utilities restricted sample site selection at some locations in Area I. Selected sample sites were located in the historic Parrott Tailings area, in the historic Butte Reduction Works tailing impoundments, and in the Colorado Tailings (Figure 4-2). Location information for impounded tailings sample sites are contained in Appendix C-2.

Drilling and sampling associated with the impounded tailings investigation was performed using a hollow stem auger drill rig equipped with a split spoon or shelby tube sampling device for soil sample collection. Samples of surface material (0 to 1 inch) and subsurface material were collected at each sample site. The surface material sample was collected using a stainless steel trowel and mixing bowl. Boring logs for impounded tailings sample sites are contained in Appendix C-3. Impounded tailings sample sites are those sites with 500 and 600 series numbers.

Subsurface samples were collected using either a split spoon or shelby tube at a depth of 1 to 18 inches below ground surface at each site and at every two foot interval below 18 inches to the total depth of the boring. Borings were advanced to at least four feet into identifiable native material underlying tailings where possible. Two borings at each of the three impounded tailings sites were advanced to at least 10 feet into identifiable native material below the tailings/native material contact. A total of 43 surface samples and 341 subsurface samples were collected from 47 locations during the impounded tailings sampling effort associated with the Phase II Remedial Investigation in Area I.

At a few drilling locations, particularly in the Parrott Tailings area, relatively thick fill material was encountered overlying tailings material. In these instances, the vertical sampling frequency was decreased because of the relative consistency of the material encountered. Planned borings at a few locations were abandoned before reaching tailings material or the underlying native material due to the presence of slag material or large cobbles and boulders which could not be drilled with the hollow stem auger drill rig.

Sampling equipment was decontaminated prior to retrieval of each sample using fresh water and a brush to remove all visible material from the sampler. Fresh water was obtained from either the Butte Sewage Treatment Plant or from the City-County Shop complex which obtain water from the city water supply. The sampling equipment was then rinsed with dilute nitric acid and deionized water.

Material samples collected utilizing a split-spoon sampler were logged and placed into zip-lock plastic bags. Material samples obtained with Shelby tube samples were logged at both ends of the sampler and the Shelby tubes were then sealed with plastic caps and duct tape. Sampling information (project, boring number, sample number, depth, date and time, and samplers) was written in permanent ink on each sample bag or shelby tube. Samples were stored in coolers under chain-of-custody in the field and upon transport to the sample staging area. Samples were stored at the sample staging area in a locked storage cabinet.

Sample splits from subsamples of each of the collected samples were analyzed with a XRF in accordance with procedures described in Section 4.1.4. These data in conjunction with collected field data were used to select those samples for laboratory analysis. Laboratory analyses of shipped samples included those for total metals, metals by grain size, water soluble metals, hexavalent chromium, EP toxicity and X-ray diffraction. The rationale for completing these types of analyses is presented in the project sampling and analysis plan (CH2M HILL, 1989d).

Selection of samples for each type of laboratory analysis was completed in consideration of all information obtained during the sampling event. This information included material types, field determined grain size, material distribution, the soils/waste material map, and XRF predicted metals concentrations. In addition, lithologic logs for each sample location were prepared and cross-sections through several sampling sites were developed to aid in selecting samples for laboratory analysis.

4.1.4 XRF Analysis

A portable X-ray fluorescence (XRF) X-Met 440 instrument, manufactured by Columbia Scientific Instruments, was used to analyze subsamples of all material samples collected during both the dispersed tailings and impounded tailings investigations. The instrument

was used primarily as a screening tool to predict concentrations of arsenic, copper, zinc, lead, chromium, and cadmium in collected samples. These data provided a basis for selecting samples for laboratory analysis.

Each sample collected during the contaminated soils/tailings investigation was homogenized by disaggregation and mixing. Approximately 100 grams of each sample were split from each homogenized sample for XRF analysis. The subsample obtained from each sample was then placed into aluminum lined paper cups, placed in an oven operated at a temperature of 40°C, and dried. Dried samples were then disaggregated, if necessary, using a rubber tipped pestle in a ceramic mortar.

Calibration procedures for the X-Met 440 XRF followed four basic steps, as outlined in the instrument's operation manual. These included:

- Exposure of XRF source probe to pure element standards

- Exposure of XRF source probe to calibration standards

- Entry of calibration standard laboratory determined metals concentration data into XRF

- Model development

Pure element standards for a variety of elements were exposed to the XRF source probe. This allowed spectrums of these elements to be stored by the XRF. Calibration standards were then exposed to the XRF source probe and laboratory determined concentrations of arsenic, cadmium, chromium, copper, lead, and zinc in the calibration standards were input into the XRF. Calibration standards selected for use during this investigation exhibited physical characteristics and metals levels similar to those expected in natural samples collected. Calibration standards used for this investigation were obtained from other areas within the Silver Bow Creek CERCLA site (Appendix C-5).

After all these data were input to the XRF, a model was developed which best predicted concentrations of each of the six elements selected for evaluation. For this study, the elements selected for input were arsenic, cadmium, chromium, copper, lead, and zinc.

Four separate models (numbered 1 through 4) were developed to predict concentrations of arsenic, cadmium, copper, zinc, iron, and chromium within specific concentration ranges. Models 1 and 4 were developed to calibrate the XRF instrument with a cadmium 109 probe using calibration samples which contained medium to high concentrations of copper, zinc, arsenic, and lead. Model 2 was also developed for use with the cadmium 109 probe but with calibration samples which contained relatively low concentrations of copper, zinc, arsenic, and lead. Model 3 was developed using an americium probe with the XRF utilizing calibration samples with the available range of cadmium concentrations. Table 4-2 contains summary statistics of metal concentration data of samples used for calibration of the four models used during XRF analyses of the various elements.

All XRF predicted concentrations for cadmium were obtained using model 3 in conjunction with the americium source probe. As stated previously, models 1 and 4 were both developed for medium to high concentrations of copper, zinc, arsenic, and lead. After model development, both models 1 and 4 were checked against samples with known metals concentrations which were not used in calibrating the models. Model 4 was as accurate or more accurate than model 1 in predicting concentrations of copper, zinc, arsenic, and lead for all check samples and was therefore selected for use in analyzing samples collected from Area I. Model 2 was used to predict element concentrations in samples with relatively low concentrations of copper, zinc, arsenic, and lead. Table 4-2 summarizes calibration parameters for each model. Listings of material samples and concentrations of metals used to calibrate each model are contained in Appendix C-5.

Daily calibration checks were completed while XRF analyses were being completed. These checks consisted of exposing three calibration check standards to the appropriate source for 400 seconds after the XRF instrument was turned on and allowed to warm up for 30 minutes. The three check standards used were representative of relatively high, medium, and low metals concentrations.

TABLE 4-2

SUMMARY OF CALIBRATION PARAMETERS, MODELS 2, 3, AND 4
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Element	Independent Variable	Slope	Intercept	Number of Standards	Correlation Coefficient	Standard Deviation	Concentration Range (mg/kg)	IDL[1]	Instrument Repeatability[2]
Model 2									
As	As	13.7	-987	20	0.982	21	12-461	63	24
	Pb	6.78		(delete #3)[4]					
	BS[3]	0.89							
Cr	Cr/BS	-607	32	20	0.4	16	4-75	48	1.5
	Fe	-0.03		(delete #21)[4]					
	Pb	0.4							
Cu	Cu	27.4	892	21	0.93	83	35-811	249	69
	Cr	-42.2							
	Mn	-19.3							
Pb	Pb	7.2	21.6	20	0.87	86	16-614	258	24
	Zn	11.6		(delete #9)[4]					
Zn	Zn	27.4	13	21	0.95	80	71-938	240	72
	Cr	-29.5							
	Fe	1.1							
Model 3									
Cd	Cd	6.2	-6.7	28	0.95	NR[5]	0.5-40	NR[5]	5.4
	Cu	-0.01		(delete #2)[4]					
	Zn	0.1							
	Hg	-2.2							
	Cd/BS[3]	-10,546							
Model 4									
As	As/BS[3]	1586	-0.09	28	0.97	90	12-1755	270	42
	Pb	0.53		(delete #'s 1, 18)[4]					
Cr	Cr	0.07	1.4	28	0.93	1.1	4-142	3.3	2.1
	Pb	0.04		(delete #'s 4, 23)[4]					
	As	0.03							

TABLE 4-2--continued

SUMMARY OF CALIBRATION PARAMETERS, MODELS 2, 3, AND 4
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Element	Independent Variable	Slope	Intercept	Number of Standards	Correlation Coefficient	Standard Deviation	Concentration Range (mg/kg)	IDL[1]	Instrument Repeatability[2]
Model 4									
Cu	Cu	-15.4	99	27	0.995		35-82,600		
	Cu/BS[3]	18,677		(delete #'s 2,9,10)[4]					
	Pb	-1.9							
	Zn	1.6							
Pb	Pb	2.8	-26	28	0.974	14.8	16-1,986	44.4	36
	As	0.5		(delete #'s 4,9)[4]					
	Zn	0.1							
Zn	Zn	-15.7	12.7	28					
	Zn/BS[3]	1.8		(delete #'s 17,24)[4]	0.981	54	49-11,100	162	207
	Cu	-0.8							

NOTE: 1 Instrument Detection limit (3 x Standard Deviation)

2 Instrument repeatability is standard deviation of ten measurements of one undisturbed sample

3 BS = backscatter

4 See Appendix C-5

5 Not Recorded

Predicted metals concentrations for the check standards were recorded and compared to ranges of predicted concentrations considered acceptable. An acceptable range of predicted concentrations relative to the calibration standard was calculated using predicted concentrations for the three samples obtained from ten 400-second exposures of the samples. A value of two times the standard deviation above and below the mean predicted concentration obtained in the 10 exposures was considered acceptable to begin sample measurements.

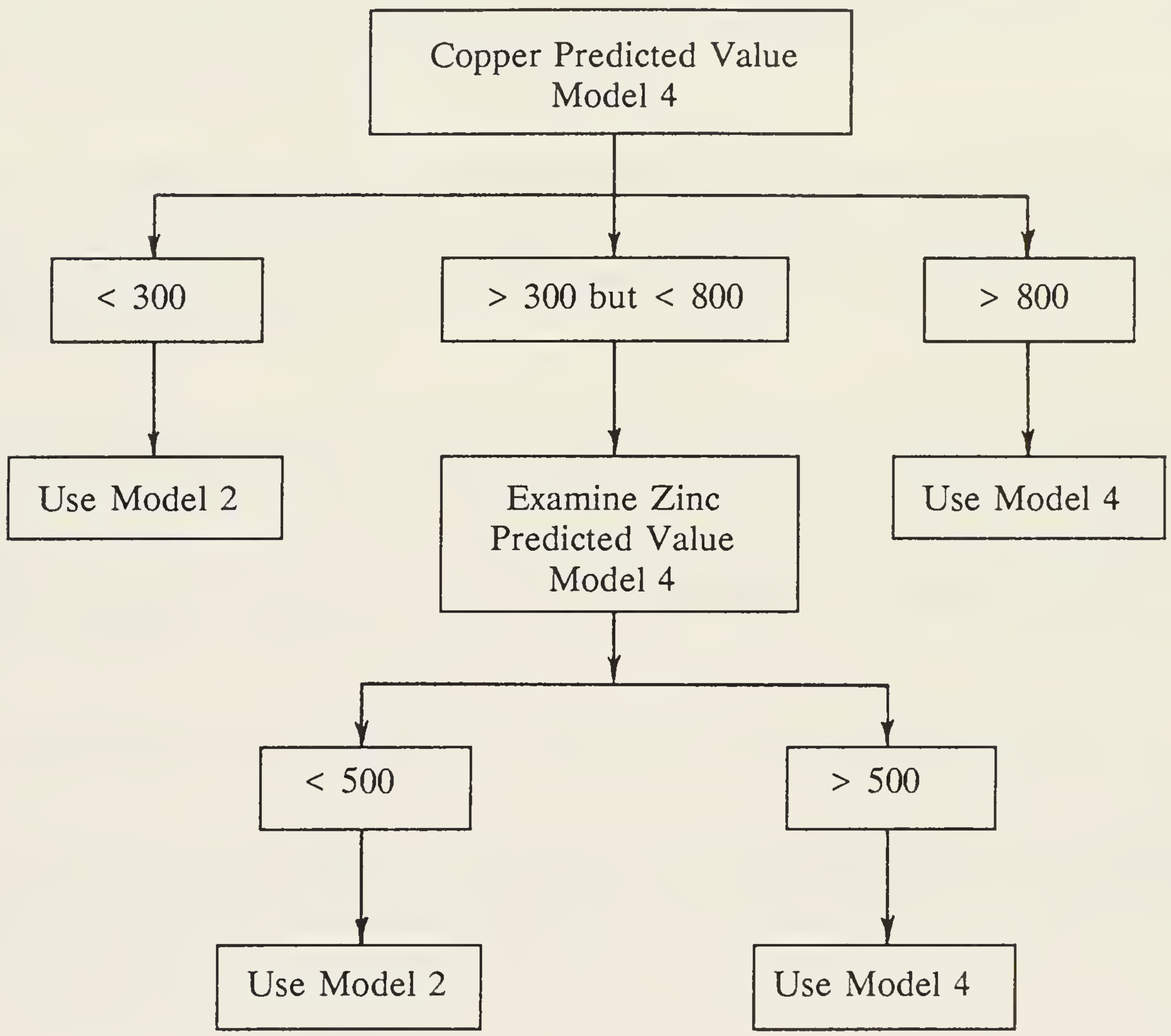
Additional calibration checks were completed during the course of sample analysis. These checks consisted of exposing two of the three check standards for 100 seconds after each 10 exposures of natural samples. If predicted concentrations of elements in the check samples were outside the acceptable limits (two times the standard deviation as determined from the 10 - 400 second exposures), the predicted concentrations for the element(s) outside the limits for the five previous samples and five following samples were used with discretion in selecting laboratory samples. Duplicate exposures of natural samples were also performed at a frequency of one in 20. Natural material samples were exposed to the source for 100 seconds.

A decision-making protocol was established to serve as a guide in selecting appropriate models for the various samples analyzed with the XRF during the Phase II Remedial Investigation. The decision framework was based on elemental concentrations used to develop each model and the relative elemental concentrations in the sample being analyzed. The model selection flow chart for XRF analyses is presented in Table 4-3.

Predicted copper concentrations from model 4 were selected as the starting point in the model selection process because a wide range of copper concentrations were used to calibrate model 4 and checks of predicted element concentrations on samples indicated that the predicted copper concentration derived through use of model 4 was consistently the most accurate. When the predicted copper concentration was in the mid-range (300 mg/kg to 800 mg/kg), the predicted concentration of zinc in model 4 was used to decide between model 2 and 4 (Table 4-3) because predicted concentrations of zinc also appeared to be relatively accurate.

TABLE 4-3

XRF MODEL SELECTION FLOW DIAGRAM
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION



Instrument detection limits (IDL) for XRF instruments have been calculated as three times the standard deviation of the counting statistic (Chappell, et. al, 1986, Piorek and Rhodes, 1987). The instrument detection limit (IDL) varies as a function of both measurement time, sample matrix, and model used. For this investigation, an IDL of three time the standard deviation of the counting statistic was used (Table 4-2). Instrument repeatability (Table 4-2) was taken as one standard deviation of a series of ten measurements taken on the same undisturbed sample (Piorek and Rhodes, 1987).

Table 4-4 summarizes results of linear regression analyses comparing XRF predicted concentrations to laboratory-determined concentrations for 222 samples from this study. No correlation for chromium could be made. Scatter diagrams for the regression analyses are contained in Appendix C-5.

It is emphasized that XRF predicted concentration data were used in this study as a screening tool to select samples for laboratory analysis. XRF predicted concentrations presented in this report should be considered only as estimates of metals concentrations in sampled material. Numerous factors, including chemical composition, matrix effects, and particle size affect predicted values.

4.2 CHANGES TO THE PROJECT SAMPLING AND ANALYSIS PLAN

This section describes changes to the project sampling and analysis plan (CH2M HILL, 1989d) which resulted from the actual performance of field activities in Area I. Rationale for implementing these changes are is also presented herein.

4.2.1 Dispersed Tailings Investigation

The project sampling and analysis plan (CH2M HILL, 1989d) indicated that a remote sensing evaluation of the Area I Operable Unit would be completed in conjunction with site mapping and as a precursor to soils sampling. Because of difficulties encountered in obtaining necessary imagery and remote sensing data for the operable unit from the USEPA, the remote sensing evaluation of Area I was not completed.

TABLE 4-4

SUMMARY OF LINEAR REGRESSION ANALYSES COMPARING XRF PREDICTED CONCENTRATIONS TO LABORATORY-DETERMINED CONCENTRATIONS FOR SELECTED METALS; AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

	Regression		Correlation Coefficients
Element	Slope	Intercept	R
Arsenic	0.67	99.5	0.89
Cadmium	0.69	11.3	0.70
Chromium	0.54	28.5	0.70
Copper	1.28	261.6	0.94
Lead	0.74	289.4	0.89
Zinc	1.20	-327.7	0.87

Note: XRF = Independent Variable
Lab = Dependent Variable
Number of samples (N) = 222

Example: $As_{Lab} = (0.67) \times (As_{XRF}) + 99.5$
Number of Samples (N) = 222

Use of remote sensing in Area I was intended to supplement on-ground mapping activities. Because remote sensing analyses were not completed, the level of understanding of site characteristics and contaminant distribution afforded by this work task were not realized during completion of the Phase II Remedial Investigation.

Several anticipated sampling sites presented in the project sampling and analysis plan (CH2M HILL, 1989d) were not sampled during the Phase II Remedial Investigation in Area I owing to site access constraints. Subsurface sampling intervals and frequencies were also changed at several sampling sites from that presented in the project sampling and analysis plan because sample site lithologies were either consistent or were not conducive to prescribed interval sampling.

Sampling methods used during dispersed tailings/contaminated soils field investigations were similar to that presented in the project sampling and analysis plan with one exception. Material present in the lower Metro Storm Drain area was not conducive to hand sampling techniques. Samples of material from this area were obtained using a backhoe to obtain access to the subsurface. Samples at these sites were collected either at the face of the exposed soil pit or from the interior of the backhoe bucket for samples collected at depths greater than about six feet below ground surface.

Numbers of samples submitted for analyses of various parameters were generally similar to those presented in the project sampling and analysis plan (CH2M HILL, 1989d). Methods used to analyze the various parameters in soils and tailings were also similar to that presented in the project sampling and analysis plan with one exception. The procedure for analyzing total metals by grain size was altered slightly from that anticipated for the project.

Samples analyzed for total metals by grain size were wet sieved from the bulk sample into two size fractions including -80 to +200 mesh and -200 mesh. Deionized water was used during the wet sieve process; this water was collected from each phase of the sieving process. The total volume of the resultant rinse water was determined. The water was then composited and a subsample was submitted for analysis of total metals.

Hydrometer analyses of grain sizes to determine weight percentages of material less than 10 micron were also performed on samples for which total metals by grain size were completed.

4.2.2 Impounded Tailings Investigation

Locations of impounded tailings sampling sites generally corresponded to locations presented in the project sampling and analysis plan (CH2M HILL, 1989d). Final sampling locations were identified following review of surface geophysical data, historic aerial photographs, and underground utility locations. The total number of sampling locations at each of the three impounded tailing sites was increased over that anticipated in the project sampling and analysis plan to further define the limits of contamination. This resulted in the addition of five sample sites at the Colorado Tailings, three sites at the Butte Reduction Works tailing impoundments, and five sites in the vicinity of the Parrott Tailings.

The project sampling and analysis plan (CH2M HILL, 1989d) indicated that all borings drilled as part of the impounded tailings investigation would continue to at least four feet into identifiable native material underlying tailings material. Several borings in the Butte Reduction Works tailing impoundments area did not encounter identifiable tailings material and the borings were terminated in what was believed to be native or uncontaminated sand material. Subsequent XRF and laboratory analyses of this material indicated metals concentrations higher than native material encountered in other borings in the area. Because of this, several borings were probably terminated in fluvially transported sand and not in native material.

The total number of samples derived from the impounded tailings investigation and which were analyzed with the XRF was 384. This was more than the 250 to 300 anticipated in the sampling and analysis plan (CH2M HILL, 1989d). The increased number of samples analyzed with the XRF was primarily due to the increase in the number of sample locations and because material retrieved from individual single split-spoon samples was occasionally split into more than one sample. Splitting of samples was completed in the field by material types to better identify characteristics of different material types encountered.

The total number of samples submitted for laboratory analysis of various parameters varied only slightly from estimates presented in the project sampling and analysis plan (CH2M HILL, 1989d).

4.3 PRESENTATION OF DATA/RESULTS

Data resulting from dispersed tailings/contaminated and impounded tailings investigations are presented in this section in several different formats. The first subsection presents and summarizes data resulting from analyses of surficial (0 to 1 inch) materials. This depth-dependent summary was segregated from other discussions to provide a basis from which certain public health and environmental issues relating to direct contact and inhalation can be evaluated.

Subsurface metals data are generally discussed and summarized in this section by identified material units within discrete geographic areas in the operable unit. These geographic areas include the upper Metro Storm Drain area, the lower Metro Storm Drain area, the manganese stockpile area, the Colorado Tailings area, and the area west of the Colorado Tailings. These geographic divisions appeared appropriate for the Area I Operable Unit based on the material type consistency within each geographic area and the uniqueness of materials within each geographic areas with respect to the balance of the site; the data are amenable to other types of groupings.

Certain analyses (e.g. EP toxicity, X-ray diffraction, bulk density, and acid-base account) were completed only on a few samples collected site-wide. Because of the few analyses available for these parameters, discussion of these results is not amenable to presentation by geographic location. Presentation and discussion of these types of data are presented near the end of this section.

Most data presented in this section are organized and compared by material type or lithologic unit. Each material unit represents a definable material type which was differentiated from other units by lithology, location, and/or stratigraphic relationships. Chemical data presented herein are grouped by these material units. Descriptions of material units established for soils and mine waste materials encountered in Area I are presented in Table 4-5.

The user of metals concentration maps contained in this report is cautioned that the reported concentration is valid only for the point of sample collection. The fact that

TABLE 4-5

DESCRIPTION OF MATERIAL UNITS FOR SOILS AND TAILINGS INVESTIGATIONS; AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

MATERIAL UNIT NO.	SUB-UNIT NO.	MATERIAL TYPE	DESCRIPTION
1		Exposed Tailings	Consist of the upper one inch of tailings material. Lithology is typically a sandy silt or a silty sand. Exposed tailings are typically barren of vegetation and are characterized by a yellow to orange brown color and may be overlain by thin deposits of white or blue metallic salts.
2		Covered Tailings	Covered tailings consist of tailings material which is overlain by one or more inches of tailings material or another lithologic unit. Covered tailings are typically a sandy silt or a silty fine- to coarse-grained sand. Covered tailings are generally yellow, yellow brown, orange brown or orange and may exhibit some color or grain-size stratification.
3		Manganese Flue Dust	Manganese flue dust is characterized by a dark brown to black silt with fine sand. This material unit is generally confined to a specific area within the manganese stockpiles area.
4		Alluvium/Tailings	Alluvium/tailings are comprised predominantly of thinly bedded, medium to very fine grained sand with silt. Alluvium/tailings deposits are typically brown with interbedded yellow, orange, and yellow brown lenses and are generally located above native materials (lithologic units 8A or 8B) and are typically associated with tailing materials. These deposits have the appearance of natural sediment mixed with tailings material.
5		Railroad Bed Fill	Railroad bed fill material is characterized by pyritic-rich altered granitic sand, gravel, and boulders. Railroad bed fill material is typically very coarse and often contains copper carbonates and iron oxides and copper sulfates deep within the roadbed core.

TABLE 4-5--continued

DESCRIPTION OF MATERIAL UNITS FOR SOILS AND TAILINGS INVESTIGATIONS; AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

6		Transported Fill	
	6A	Sand, Gravel, Colluvium	This lithologic unit is a subset of the transported fill unit and typically consists of brown to orange brown silt, sand, gravel, and minor cobbles. This material has been transported and is generally located in filled areas (as determined from early mapping and air photographs). The unit typically overlies soil horizons or organic horizons.
	6B	Manganese Ore Piles	Deposits associated with the manganese ore pile lithologic unit are located in the manganese stockpile area and consist of black sand, gravel and angular fragments to 4 inches. The color of the material is charcoal black with pink molting on large fragments.
	6C	Slag and Slag Sand and Gravel	This lithologic unit consists of black slag material either deposited as a homogeneous mass or broken into sand, gravel, and cobble sized fragments. This material type is typically found in and adjacent to areas of historic smelting activity.
	6D	Demolition/Land-fill Debris	Demolition/Landfill debris typically consists of broken concrete, building materials, and other landfill waste (paper, garbage, etc.).
	6E	Waste Rock	Waste rock fill is characterized by gravel, cobbles, boulders, and sand of altered granite.
7		Exposed Native Soil	Exposed native soil is characterized by a thin soil/organic horizon overlying native sediment or colluvium. Samples of native soil were obtained from the upper one inch of the soil profile.

TABLE 4-5--continued

DESCRIPTION OF MATERIAL UNITS FOR SOILS AND TAILINGS INVESTIGATIONS; AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

8		Covered Native Soil/Sediment	
	8A	Organic Silt and Clay, including peat	This lithologic unit is typically comprised of organic rich silts, clays, and/or peat which has been covered by other material types. This unit is generally present in the low lying areas and overlies native sand, silt, and gravel (8B).
	8B	Sand, Gravel, and Silt (upper two feet)	Material included in this lithologic unit includes the upper two feet of native sand, silt, and gravel. This material unit is typically brown to light yellow brown and contains stratified lenses of silty sand, sandy silt, and sandy gravel.
	8C	Sand, Gravel, and Silt (below unit 8B)	This lithologic unit includes all native silt, sand, and gravel material located greater than two feet below the top of native silt, sand, and gravel material (beneath 8B).

element concentration lines were not placed on the maps indicates that we do not believe the intensity of data points is sufficient to interpolate metal levels.

4.3.1 Surface Soils/Tailings

Surface soils/tailings data presented in this section includes those analyses completed on samples obtained from either surface to one-inch depths or occasionally surface to two-inch depths. These samples represent those materials which can be easily contacted by humans and which are subject to surface erosion and airborne entrainment.

4.3.1.1 Surface Lithologies

Exhibit II is a surface materials map which depicts the various material units identified within the Area I Operable Unit. Supporting information used in preparing Exhibit II is contained in Appendix C-1. Surficial lithologic map units within Area I (Exhibit II) include the following: (unit 1) - exposed tailings; (unit 3) - manganese flue dust; (unit 4)- alluvium/tailings; (unit 5) - railroad bed fill; (unit 6) - transported fill (all subdivisions); and, (unit 7) - exposed native soils/sediment. Table 4-5 describes physical characteristics of materials associated with these material units.

In general, most of the Metro Storm Drain in the upper half of Area I is covered with imported fill material comprised of either waste rock or landfill debris. Some small areas north of the Metro Storm Drain exhibit exposed tailings which are probably remnants of exposed tailings identifiable on 1955 aerial photographs of the area (Figure 4-1). Surficial materials in the lower portion of the operable unit consist of a variety of mine and mill wastes generally consisting of exposed tailings and coarser mine waste materials and manganese slag.

Grain size analyses of surficial materials sampled in Area I are presented in Appendix C-4. Twenty-eight surface samples were analyzed for grain size through the -200 sieve size and 14 surface samples were analyzed for grain size through the five micron particle size by hydrometer testing. These data indicate the surficial material in Area I vary from silty sand with gravel to silt and clay with fine sand. Material units 1 (exposed tailings), 4 (mixed

alluvium-tailings), and 3 (manganese flue dust) contained a relatively greater proportion of -200 mesh material than other surficial material units in Area I.

4.3.1.2 Surficial Chemistry

Total Metals

Appendices C-5 and C-6 contain soils/tailings data bases for XRF and laboratory analyses, respectively. Figures 4-3 through 4-5 graphically depict XRF-predicted concentrations and laboratory-determined concentrations of arsenic, lead, and cadmium, respectively, in surficial material in the Metro Storm Drain area. Figures 4-6 through 4-8 illustrate XRF predicted concentrations and laboratory concentrations of arsenic, lead, and cadmium, respectively, for the lower portions of Area I. Table 4-6 is a statistical summary of XRF and laboratory-determined concentrations arsenic, chromium, copper, lead, zinc, and cadmium for sampled surficial materials, grouped by material units.

These data indicate there are few identifiable trends to the distribution of metals concentrations laterally within individual material units and between material units. Average metals concentrations for each material unit (Table 4-6) probably provides the best means of evaluating the relative distribution of metals in Area I surficial materials.

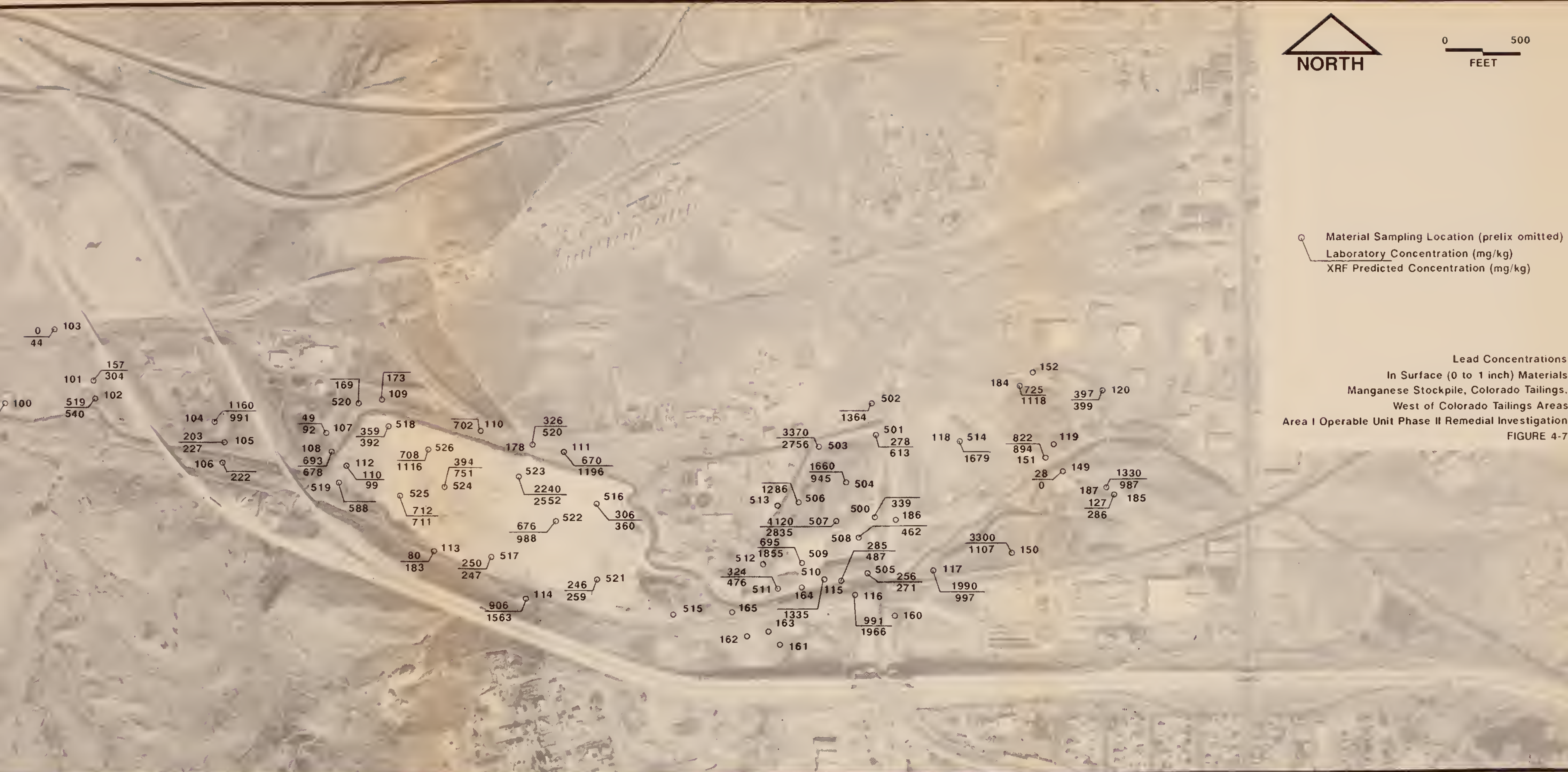
Metals data (Table 4-6) indicate relatively higher concentrations of copper, lead, and zinc were measured in exposed tailings (unit 1) and in mixed alluvium-tailings (unit 4) as compared to other material units within Area I. Geometric mean concentrations of these metals in the two tailings units were on the order of 1200, 470, and 2300 mg/kg, respectively. Railway roadbed fill exhibited a relatively high concentration of copper (laboratory geometric mean of 1512 mg/kg). Highest arsenic concentrations in surficial materials was in slag material (unit 6C) which exhibited a geometric mean laboratory-determined arsenic concentration of 648 mg/kg. Some samples of demolition and landfill debris (unit 6D) obtained from the lower Metro Storm Drain area contained relatively high concentrations of copper, lead, and zinc as compared to other transported fill material units.

Arsenic Concentrations
in Surface (0 to 1 inch) Materials
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-3

Lead Concentrations
in Surface (0 to 1 inch) Materials
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-4

Cadmium Concentrations
in Surface (0 to 1 inch) Materials
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-5

Arsenic Concentrations
in Surface (0 to 1 inch) Materials
Manganese Stockpile, Colorado Tailings,
West of Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-6



Lead Concentrations
In Surface (0 to 1 inch) Materials
Manganese Stockpile, Colorado Tailings,
West of Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-7

Cadmium Concentrations
in Surface (0 to 1 inch) Materials
Manganese Stockpile, Colorado Tailings,
West of Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-8

TABLE 4-6
STATISTICAL SUMMARY OF XRF AND LABORATORY DATA
OF SURFACE MATERIAL (0 - 0.17 FT)

AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
1	Exposed tailings												
	Geometric Mean	< 486	425	13	5	< 18	< 2	< 1227	955	< 534	478	1453	2058
	Arithmetic Mean	< 687	601	17	9	< 19	< 3	< 2281	1523	< 800	644	2660	2854
	Standard Deviation	401	453	16	8	7	2	1977	1309	410	549	3640	2566
	Maximum	1703	1580	57	29	34	11	7101	3980	2552	2240	13300	10200
	Minimum	< 275	54	4	0	< 5	< 1	< 31	127	< 247	80	327	275
	Total No. of Samples	15	14	15	14	15	14	15	14	15	14	15	14
	No. Above Detection	13	14	15	14	13	9	14	14	9	14	15	14
2	Covered tailings												
	Geometric Mean	1417	2050	32	30	< 6	2	14572	13558	1483	848	9142	8491
	Arithmetic Mean	1796	2608	34	32	< 11	2	17836	14995	1542	858	10930	8885
	Standard Deviation	1561	2280	12	17	0	0	14544	9058	600	188	8472	3698
	Maximum	2900	4220	42	44	21	2	28120	21400	1966	991	16920	11500
	Minimum	692	996	25	20	< 21	2	7551	8590	1118	725	4939	6270
	Total No. of Samples	2	2	2	2	2	2	2	2	2	2	2	2
	No. Above Detection	2	2	2	2	1	2	2	2	2	2	2	2
3	Manganese flue dust												
	Geometric Mean	336	758	11	14	< 4	< 1	< 59	440	1051	2563	5568	4409
	Arithmetic Mean	340	761	12	15	< 5	< 1	< 59	477	1052	2645	5633	4510
	Standard Deviation	76	93	1	7	0	0	0	260	78	926	1202	1344
	Maximum	394	827	12	19	9	0	0	660	1107	3300	6483	5460
	Minimum	286	695	11	10	< 9	< 0	< 0	293	997	1990	4783	3560
	Total No. of Samples	2	2	2	2	2	1	2	2	2	2	2	2
	No. Above Detection	2	2	2	2	1	0	0	2	2	2	2	2
4	Alluvium / Tailings												
	Geometric Mean	< 172	252	< 14	< 5	< 25	< 8	< 1799	1313	< 527	479	2487	2674
	Arithmetic Mean	< 230	306	< 24	< 10	< 26	< 11	< 3135	1936	< 735	773	4733	4217
	Standard Deviation	85	253	27	11	8	9	3876	1797	479	954	6902	4737
	Maximum	838	1260	120	61	53	50	17260	8440	2835	4120	29840	23300
	Minimum	< 283	89	< 4	< 1	< 10	< 4	< 379	96	< 462	63	324	318
	Total No. of Samples	34	26	34	26	34	23	34	26	34	26	34	26
	No. Above Detection	9	26	32	22	32	22	33	26	23	26	34	26
5	Railway roadbed fill												
	Geometric Mean	< 174	219	6	< 0	< 23	5	< 625	898	< 359	217	555	564
	Arithmetic Mean	< 243	298	6	< 3	< 23	5	< 1029	1389	< 447	421	687	857
	Standard Deviation	94	204	3	0	3	2	1198	1745	80	454	466	977
	Maximum	634	617	12	20	26	8	4204	5650	987	1330	1558	3160
	Minimum	< 288	38	4	< 20	< 17	3	< 345	177	< 581	28	171	133
	Total No. of Samples	8	8	8	8	8	8	8	8	8	8	8	8
	No. Above Detection	3	8	8	1	7	8	7	8	3	8	8	8

NOTES: 1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

LE 4-6
STATISTICAL SUMMARY OF XRF AND LABORATORY DATA
OF SURFACE MATERIAL (0 - 0.17 FT)

AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
6A	Transported fill: Natural Alluvium												
	Geometric Mean	< 50	71	< 5	< 2	< 26	9	< 371	334	< 200	167	< 471	880
	Arithmetic Mean	< 65	113	< 7	< 4	< 26	11	< 539	552	< 286	265	< 911	1571
	Standard Deviation	49	87	4	1	2	8	325	411	132	195	960	1477
	Maximum	0	302	18	7	42	32	1789	1210	1679	649	4672	3940
	Minimum	< 0	6	< 2	< 2	< 24	5	< 252	41	< 306	18	< 262	93
	Total No. of Samples	28	11	28	11	28	11	28	11	28	11	28	11
	No. Above Detection	0	11	24	7	9	11	20	11	6	11	21	11
6C	Transported fill: Sand / gravel with slag												
	Geometric Mean	1999	3530	8	< 0	< 2	< 0	< 59	312	613	278	1079	728
	Arithmetic Mean	1999	3530	8	< 0	< 2	< 0	< 59	312	613	278	1079	728
	Standard Deviation	0	0	0	0	0	0	0	0	0	0	0	0
	Maximum	1999	3530	8	0	0	0	0	312	613	278	1079	728
	Minimum	1999	3530	8	< 0	< 0	< 0	< 0	312	613	278	1079	728
	Total No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1
	No. Above Detection	1	1	1	0	0	0	0	1	1	1	1	1
6E	Transported fill: Waste rock												
	Geometric Mean	< 135	(4)	8	(4)	22	(4)	822	(4)	< 222	(4)	730	(4)
	Arithmetic Mean	< 135	(4)	8	(4)	22	(4)	822	(4)	< 222	(4)	730	(4)
	Standard Deviation	0	(4)	0	(4)	0	(4)	0	(4)	0	(4)	0	(4)
	Maximum	0	(4)	8	(4)	22	(4)	822	(4)	0	(4)	730	(4)
	Minimum	< 0	(4)	8	(4)	22	(4)	822	(4)	< 0	(4)	730	(4)
	Total No. of Samples	1		1		1		1		1		1	
	No. Above Detection	0		1		1		1		0		1	
7	Native soils: Shallow; 0 - 1 in. depth												
	Geometric Mean	< 89	86	11	5	< 28	9	741	528	< 432	470	1535	1024
	Arithmetic Mean	< 105	97	13	5	< 28	10	849	570	< 561	565	2414	1101
	Standard Deviation	51	52	7	1	3	5	460	229	308	313	2159	411
	Maximum	0	149	23	6	37	15	1447	811	1364	830	5685	1440
	Minimum	< 0	45	5	3	< 26	4	348	269	< 276	154	355	505
	Total No. of Samples	7	4	7	4	7	4	7	4	7	4	7	4
	No. Above Detection	0	4	7	4	5	4	7	4	5	4	7	4

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

Metals by Grain Size

Total metals by grain size data were collected to determine the relative concentrations of metals in various size fractions associated with surficial materials in Area I. The two primary size fractions for which total metals were determined included the -80 to +200 mesh fraction and the -200 mesh fraction. Appendix C-7 contains the total metals by grain size data base for Area I.

Eighteen surface samples were analyzed for metals by grain size throughout Area I. Samples selected for this analysis represented all material units exposed in the study area, including native soils. Table 4-7 summarizes relative proportions and metals concentrations for the -80 to +200 mesh and -200 mesh fractions of the samples in addition to total metal concentrations in the bulk sample used for the metals by grain size analysis. Concentrations of metals in rinseate water resulting from wet sieving of the samples is also presented in Table 4-7.

Grain size data presented in Table 4-7 indicate material units 2 (covered tailings), 4 (mixed alluvium and tailings), and 3 (manganese flue dust) often contain greater than 65% -200 mesh material. The majority of metals in these samples from these units also occurs in the finer fraction (-200 mesh) of the material. Some samples containing a relatively low proportion of -200 mesh material (less than 20%) exhibited greater than 60% of the metals in the -200 mesh fraction. An example of this relationship is sample AI-SD-114-01, obtained from the Colorado Tailings (Table 4-7). The data indicate that as particle size decreases in Area I surface materials, metals concentrations increase.

A wet sieving procedure was used to ensure maximum recovery of metals in the -200 mesh fraction. In general, the concentration of metals by weight in the rinseate water represented less than 5% of the total metals by weight in the entire sample. However, in some cases, most of the total metal content by weight in the sample was measured in the rinseate water. Examples of this are sample numbers 505-01, 509-01A, 510-01A, 184-01 and 186-01 (Table 4-7). These samples include three tailings samples, one alluvium/tailings sample, and one railway roadbed core. Only one of these five samples had a high percentage of -200 mesh material (184-01).

TABLE 4-7

SUMMARY OF TOTAL METALS AND TOTAL METALS BY GRAIN SIZE ANALYSES FOR SURFACE SOILS/TAILINGS AND SIEVE RINSEATES AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

					CONCENTRATION– mg/kg (soil) µg/l (water)							
SAMPLE NO.	AREA	DEPTH (feet)	LITHOLOGIC UNIT	MATERIAL	As	Cr	Cu	Pb	Zn	Cd	Wet Sieve %(3)	ASTM(4) Dupe Sieve
146-01	Upper Metro Storm Drain	0.0-0.1	6E	Total(1)	192	13.3	595	177	628	1.8	510.5 gm	
				-80 to +200	255	11.0	902	291	1060	0.95	0.2%	7.2%
				-200 mesh	413	18.7	1470	411	1390	1.30	0.5%	13.7%
				Rinseate(2)	42	13.0	8650	75.5	13000	62		
124-01	Lower Metro Storm Drain	0.0-0.1	4	Total	--	--	--	--	--	--	579.8 gm	
				-80 to +200	88.6	9.7	1190	244	2560	0.84	14.5%	--
				-200 mesh	229	16.4	2560	672	6870	6.1	64.3%	--
				Rinseate	11.6	34.0	1560	6	230000	537		
173-01	Lower Metro Storm Drain	0.0-0.1	4	Total	258	12.1	3420	339	5240	9	660.0 gm	
				-80 to +200	190	6.6	2190	188	3320	3.8	14.7%	--
				-200 mesh	239	11.5	3230	404	4650	5.0	70.9%	--
				Rinseate	13	10	25000	2.3	2000	28.8		
174-01	Lower Metro Storm Drain	0.0-0.1	7	Total	149	4.3	660	787	1440	5.6	323.9 gm	
				-80 to +200	161	5.8	853	959	1760	5.7	8.5%	--
				-200 mesh	428	15.4	1910	1480	3290	11.8	10.3%	--
				Rinseate	247	8.0	1460	185	1410	28.8		
177-01	Lower Metro Storm Drain	0.0-0.1	4	Total	288	16.2	2120	387	1150	0.41	395.1 gm	
				-80 to +200	151	9.1	1340	165	1010	0.42	8.0%	--
				-200 mesh	317	22.0	2110	429	958	0.40	77.1%	--
				Rinseate	18.8	12.0	14000	18	23400	68.0		
184-01	Manganese Stockpile	0.0-0.1	2	Total	996	1.6	8590	725	6270	20.4	259.0 gm	
				-80 to +200	161	0.73	197	230	101	0.37	7.2%	6.4%
				-200 mesh	938	1.4	1480	1050	746	1.10	78.1%	91.7%
				Rinseate	9600	46.0	873000	823	434000	971		

(1)Bulk soils/tailings sample analysis for total metals
(2)Deionized water used to perform modified wet sieve analysis
(3)Percent of total sample
(4)Duplicate sieve analysis using alternative ASTM C136 method

TABLE 4-7–continued

SUMMARY OF TOTAL METALS AND TOTAL METALS BY GRAIN SIZE ANALYSES FOR SURFACE SOILS/TAILINGS AND SIEVE RINSEATES AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

					CONCENTRATION– mg/kg (soil) µg/l (water)							
SAMPLE NO.	AREA	DEPTH (feet)	LITHOLOGIC UNIT	MATERIAL	As	Cr	Cu	Pb	Zn	Cd	Wet Sieve %(3)	ASTM(4) Dupe Sieve
516-01A	Colorado Tailings	0.0-0.1	1	Total(1)	552	2	520	306	2210	11	593.5 gm	
				-80 to +200	346	2	395	216	3770	13	16.5%	--
				-200 mesh	1530	7	1370	1260	5140	18	20.4%	--
				Rinseate(2)	710	25	18000	380	75000	650		
517-01	Colorado Tailings	0.0-0.1	1	Total	249	<1	219	250	1080	3	720.6 gm	
				-80 to +200	325	<1	222	203	2380	8	11.0%	--
				-200 mesh	1540	6	851	1450	4710	14	8.8%	--
				Rinseate	780	10	1900	720	2200	11		
518-01	Colorado Tailings	0.0-0.1	1	Total	216	2	644	359	1590	6	736 gm	
				-80 to +200	131	<1	224	209	2730	9	10.2%	13.5%
				-200 mesh	743	2	1190	1240	3430	13	23.3%	26.4%
				Rinseate	800	20	110000	58	110000	600		
521-01	Colorado Tailings	0.0-0.1	1	Total	265	2	484	246	2290	8	690.7 gm	
				-80 to +200	309	<1	277	242	5260	17	6.3%	--
				-200 mesh	1220	2	1090	1190	6040	19	12.8%	--
				Rinseate	1100	8	64000	130	110000	320		
524-01	Colorado Tailings	0.0-0.1	1	Total	771	2	417	394	1580	5	711.4 gm	
				-80 to +200	798	<1	387	284	3150	10	15.6%	--
				-200 mesh	2010	2	2570	1570	8920	32	8.0%	--
				Rinseate	500	8	2500	79	30000	44		
101-01	West Colorado Tailings	0.0-1.0	4	Total	325	5.1	3080	157	1410	7.6	558.3 gm	
				-80 to +200	191	4.4	2360	124	469	2.70	14.2%	--
				-200 mesh	653	8.9	7080	302	2140	12.3	23.4%	--
				Rinseate	189	125	20000	49.7	88800	492		

(1) Bulk soils/tailings sample analysis for total metals
(2) Deionized water used to perform modified wet sieve analysis
(3) Percent of total sample
(4) Duplicate sieve analysis using alternative ASTM C136 method

TABLE 4-7—continued

SUMMARY OF TOTAL METALS AND TOTAL METALS BY GRAIN SIZE ANALYSES FOR SURFACE SOILS/TAILINGS AND SIEVE RINSEATES AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

					CONCENTRATION-- mg/kg (soil) µg/l (water)							
SAMPLE NO.	AREA	DEPTH (feet)	LITHOLOGIC UNIT	MATERIAL	As	Cr	Cu	Pb	Zn	Cd	Wet Sieve %[3]	ASTM[4] Dupe Sieve
186-01	Manganese Stockpile	0.0-0.3	5	Total[1]	657	2.2	12400	937	12700	39.7	391.6 gm	
				-80 to +200	1040	3.3	6980	461	3110	6.1	6.4%	5.8%
				-200 mesh	1680	4.7	10300	4850	2950	7.5	16.5%	21.0%
				Rinseate[2]	66	31	1300000	142	1030000	2900		
505-01	Manganese Stockpile	0.0-0.1	1	Total	97	10	3980	256	1960	4	1037 gm	
				-80 to +200	106	15	1970	291	1200	2	11.2%	8.0%
				-200 mesh	283	25	7250	983	2780	4	23.9%	29.0%
				Rinseate	24	368	950000	97	441000	1270		
507-01	Manganese Stockpile	0.0-0.1	4	Total	1260	<2	3480	4120	6610	9	467.7 gm	
				-80 to +200	429	<1	3090	2080	6220	16	3.2%	
				-200 mesh	1270	5	3750	4870	7210	11	78.4%	
				Rinseate	139	200	2610	521	30800	101		
509-01A	Manganese Stockpile	0.0-0.1	4	Total	924	6	8440	695	23300	61	1213 gm	
				-80 to +200	513	7	2620	325	2390	6	8.5%	7.8%
				-200 mesh	2000	14	9060	1580	10900	31	45.2%	43.3%
				Rinseate	103	145	532000	40	3150000	4990		
510-01A	Manganese Stockpile	0.0-0.1	1	Total	338	<1	3400	1140	5580	20	705.0 gm	
				-80 to +200	148	1	141	185	1010	4	20.2%	19.6%
				-200 mesh	1850	5	2260	3110	7580	24	43.2%	47.5%
				Rinseate	370	28	420000	170	840000	4000		
114-01	Colorado Tailings	0.0-1.0	1	Total	1580	0.8	2680	906	4930	17.3	559.5 gm	
				-80 to +200	1650	1	4170	232	9730	33.1	9.2%	--
				-200 mesh	4640	1	5380	2990	6280	19.6	19.2%	--
				Rinseate	251	9	25000	152	37000	134		

(1) Bulk soils/tailings sample analysis for total metals
(2) Deionized water used to perform modified wet sieve analysis
(3) Percent of total sample
(4) Duplicate sieve analysis using alternative ASTM C136 method.

Water Soluble Metals

Water soluble metals analyses were performed on 20 surface material samples collected during the Phase II Remedial Investigation in Area I. These data are contained in Appendix C-8 and are summarized in Table 4-8. Water soluble metals analyses were performed on material samples which constitute a subset of the materials analyzed for total metals.

Water soluble metals were analyzed in surface materials to evaluate the potential impact of runoff over these materials on receiving surface water courses in Area I. These data indicate samples collected from material units 1 (exposed tailings), 4 (mixed alluvium-tailings), and 5 (railroad bed material) solubilized readily in water and produced metals concentrations relatively higher than other material units sampled. These units also contained relatively high total metals concentrations which indicates that a sizable portion of metals in these types of materials can be solubilized in water.

Material units which exhibited relatively low water soluble metals concentrations included units 6 (transported fill material) and 3 (manganese flue dust) (Table 4-8). The low concentrations in these materials is a reflection of the relatively low total metals concentrations in the host material.

Railroad Roadbed Material

Ten railroad roadbed samples were collected from various locations along abandoned rail lines with Area I. Sample locations are shown on Figure 4-2. Figure 4-9 schematically illustrates the typical composition of rail roadbeds sampled in Area I. The rail roadbeds appear to have been constructed with at least two types of material comprising the core of the structures. A waste rock ore material appears to have been used to construct the inner core and an alluvial sand and gravel type material makes up the outer core material (Figure 4-9). A cemented cap was often visible on top of the rail roadbeds in Area I, presumably a result of spillage during rail transport when the lines were operational.

Samples were collected from all three general components of the rail roadbed materials. The following list summarizes total metals concentrations for selected metals in the materials:

Sample No.	Material Type *	Concentration (mg/kg)					
		As	Cr	Cu	Pb	Zn	Cd
103-01	1	367	5.7	177	43.8	376	0.42
140-01	1	264	5.2	629	434	317	0.41
142-02	1	210	6.7	1100	157	844	0.38
149-01	1	285	7.3	800	27.8	133	0.41
151-01	1	634	2.8	1040	822	1050	0.38
151-02	2	380	0.81	2370	3800	7610	8.0
176-01	1	448	3.7	832	427	585	0.41
185-01	1	209	5.0	5650	127	394	0.39
186-01	3	406	2.2	12400	937	12700	39.7
187-01	2	91	3.4	886	1330	3160	19.5
Avg		296	4.3	2588	811	2717	7.0

* 1: Spilled Ore, Surface Material
2: Alluvial Sand and Gravel Core Material (Outer Core)
3: Waste Rock Core Material (Inner Core)

Highest concentrations of copper, zinc, lead, and cadmium were generally associated with the material making up the core of the rail roadbed. Certain samples obtained from surficial material along the roadbeds also exhibited relatively high concentrations of metals parameters.

4.3.2 Upper Metro Storm Drain

The upper Metro Storm Drain area includes the upper portion of the Area I Operable Unit from near the Weed Concentrator to Harrison Avenue (Figure 4-2). Prominent features present within this part of Area I include the City-County shop complex and the Butte Civic Center. The historic Parrott Smelter was also located in the upper Metro Storm Drain area.

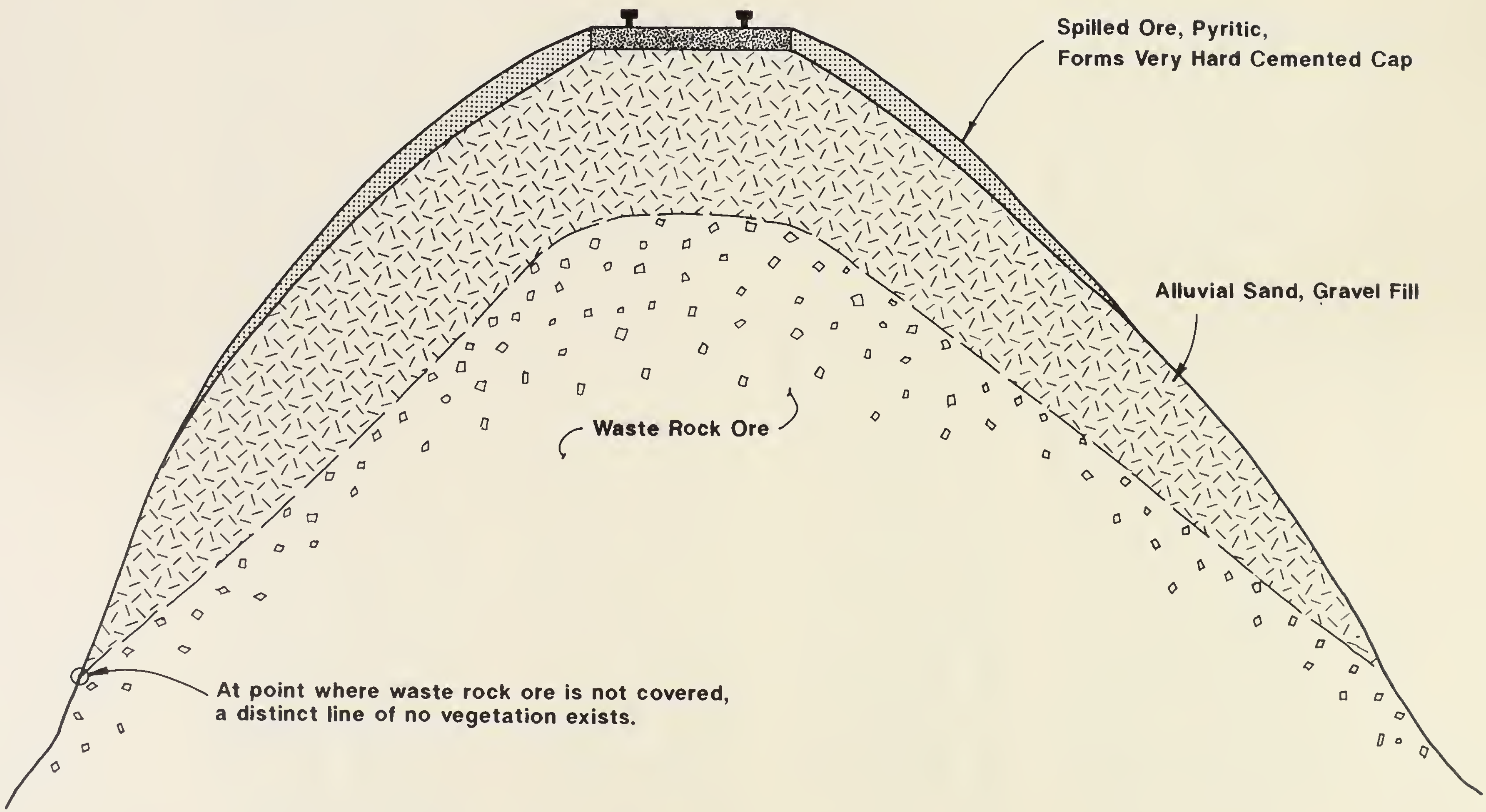
4.3.2.1 Subsurface Lithology

Historic aerial photographs (circa. 1955) show extensive slag piles and exposed tailing deposits in the upper Metro Storm Drain area (Figure 4-1). As described previously, large quantities of fill material have apparently been deposited in the area since 1955, covering

TABLE 4-8

SUMMARY OF WATER SOLUBLE METALS FOR SURFACE (0 TO 1 INCH) MATERIALS; AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

LOCATION/LITHOLOGY INFORMATION				CONCENTRATION (μg/L)					
GEOGRAPHIC AREA	SAMPLE NO.	MATERIAL UNIT	SAMPLED INTERVAL (feet)	As	Cd	Cr	Cu	Pb	Zn
Upper Metro Storm Drain	134-01	4	0-0.1	46	100	53	41,000	<0.4	21,000
Upper Metro Storm Drain	140-01	5	0-0.2	3,900	89	69	27,000	1.8	25,000
Upper Metro Storm Drain	147-01	6C/D	0-0.1	15	370	<8	730	<0.4	86,000
Lower Metro Storm Drain	121-01	4	0-0.1	7.1	220	66	3,300	<0.4	92,000
Lower Metro Storm Drain	125-01	4	0-0.2	25	280	19	750	<0.4	110,000
Lower Metro Storm Drain	126-01	4	0-0.2	110	<0.1	8.0	40	<0.4	40
Lower Metro Storm Drain	128-01	4	0-0.2	3.8	22	<8	1,300	1.3	27,000
Lower Metro Storm Drain	131-01	4	0-0.1	9.2	100	<8	57	<0.4	26,000
Lower Metro Storm Drain	145-01	4	0-0.1	130	0.11	<8	91	0.8	21
Lower Metro Storm Drain	173-01	4	0-0.1	3.8	10	<8	98	<0.4	1,400
Lower Metro Storm Drain	174-01	7	0-0.1	160	<0.1	<8	23	2.2	21
Lower Metro Storm Drain	132-01	7	0-0.1	45	0.15	10	57	1.3	22
Manganese Stockpile	505-01	1	0-0.1	3.7	470	100	370,000	<0.4	150,000
Manganese Stockpile	184-01	2	0-0.1	8,900	1,800	71	900,000	<0.4	660,000
Manganese Stockpile	117-01	3	0-0.1	9.3	<0.1	<8	<6	<0.4	86
Manganese Stockpile	151-01	5	0-0.2	12	26	14	8,100	1.3	21,000
Manganese Stockpile	186-01	5	0-0.3	20	2,000	9.0	42,000	6.7	670,000
Colorado Tailings	113-01	1	0-0.2	34	<0.1	<8	7.0	<0.4	20
Colorado Tailings	111-01	6A/C	0-0.1	9.8	360	<8	150	<0.4	39,000
Area West of Colorado Tailings	100-01	4	0-0.1	12	350	<8	23,000	<0.4	70,000



Cross Section Railway Roadbed
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-9

nearly all of the exposed tailings material and slag deposits visible on the 1955 air photographs in this portion of the operable unit.

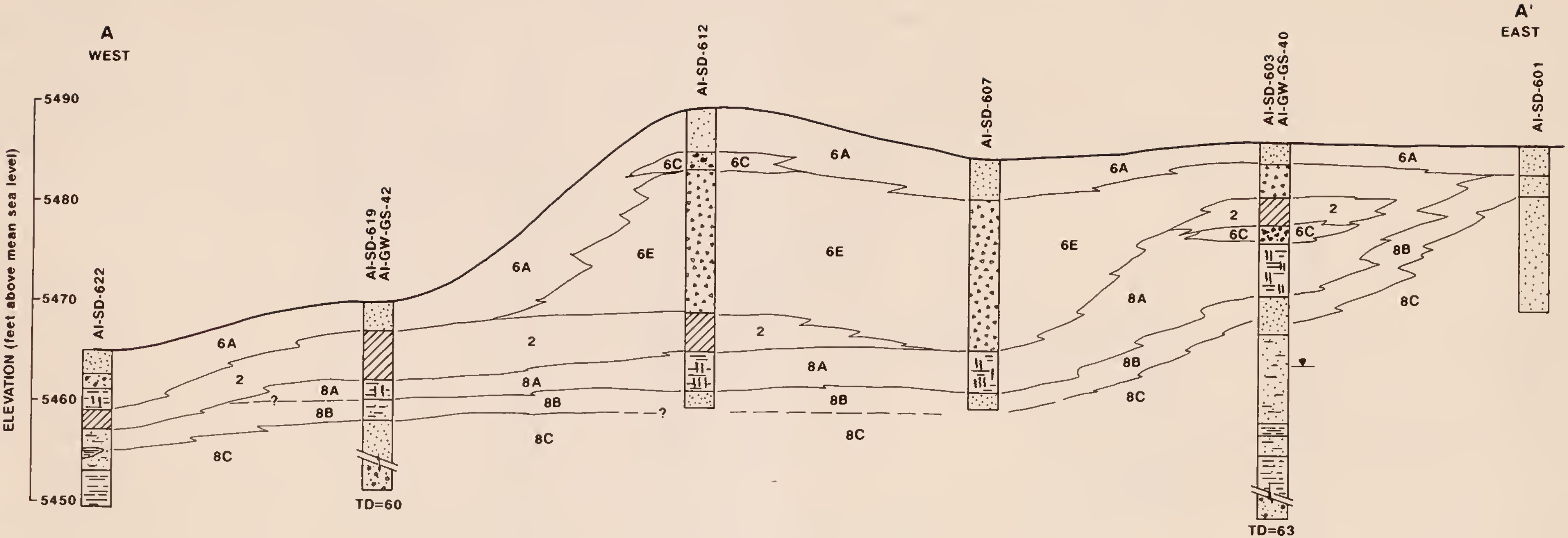
Subsurface materials encountered in soil borings in the upper Metro Storm Drain area include a variety of material units. The most prominent material types present within this portion of Area I include transported fill material (units 6A, 6C, and 6E) and covered tailings (unit 2) (Table 4-5). Lesser quantities of alluvium/tailings material (unit 4) and landfill debris (unit 6D) are also present within the area (Table 4-5). Native material units encountered in this portion of the study area included organic silts and clays (unit 8A), clay and silt (unit 8B), and sand and gravel (unit 8C) (Table 4-5).

Subsurface material units encountered in the upper Metro Storm Drain area are illustrated on a series of cross sections; locations of these cross sections are shown on Figure 4-10. Figure 4-11 (cross section A-A') is an east-west geologic cross section through the upper Metro Storm Drain area showing the distribution of material units as determined from soil borings. Elevations of borings have been estimated from survey data available from groundwater monitoring wells and are approximate.

Examination of Figure 4-11 indicates that there is a maximum of approximately 20 feet of fill material (units 6A, 6C, and 6E) overlying tailing deposits in the upper Metro Storm Drain area. The thickness of fill material decreases to the east; soil boring A1-SD-601, located at the eastern edge of the study area did not encounter fill material (Figure 4-11). Fill material also appears to thin to the west; six feet of fill material overlying two feet of tailings was encountered at soil boring AI-SD-622 (Figure 4-11).

Geologic cross section B-B' (Figure 4-12) is oriented approximately north-south along the eastern end of the upper Metro Storm Drain area. This cross section indicates that the southern extent of fill material is located between borings A1-SD-604 and A1-SD-170. The northern end of this cross section at boring A1-SD-605 is still in fill material; large cobbles and/or boulders were encountered at a depth of nine feet in this boring. Fill material is present in thicknesses of approximately 20 feet near the center of this section (Figure 4-12).

Locations of Geologic Cross Sections
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-10



EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust, silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore

Transported Fill

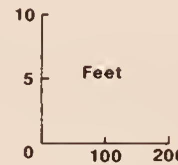
6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic

Native Soils/Sediment

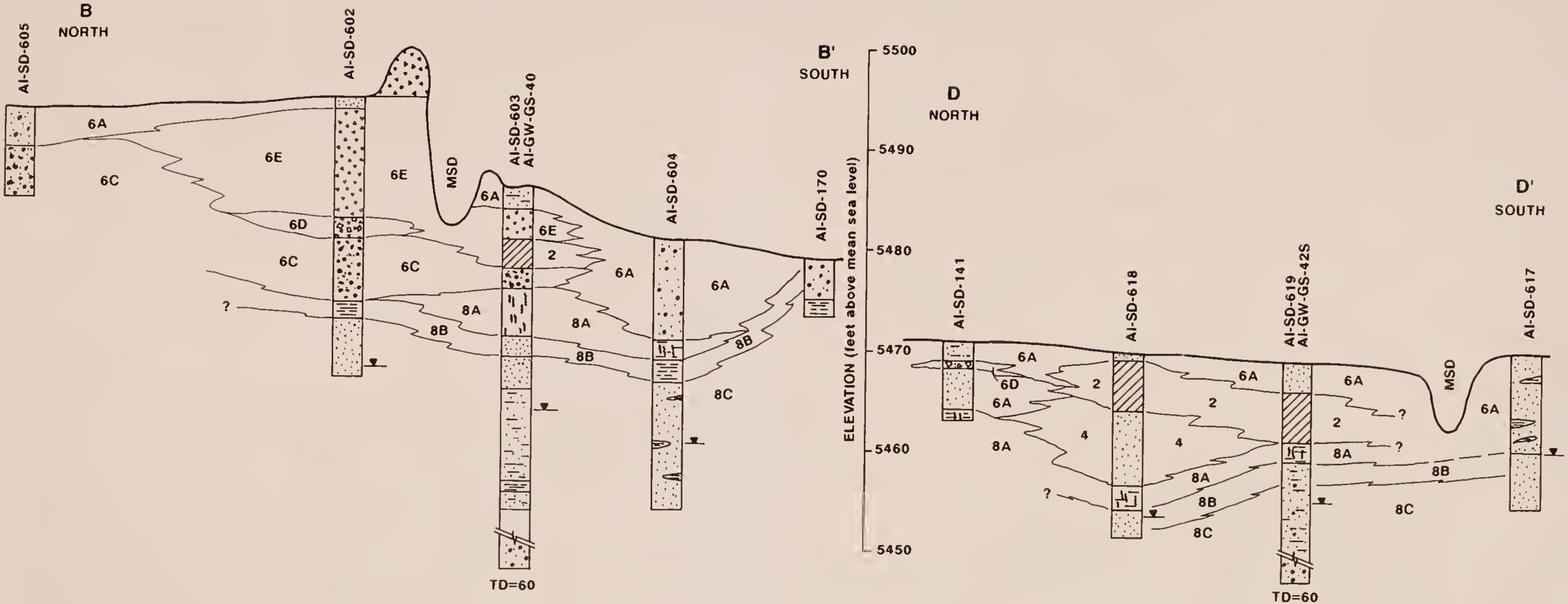
8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

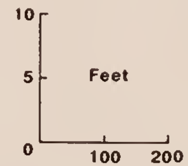
Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A



Geologic Cross Section A-A'
East-West through Upper Metro Storm Drain Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-11





EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings, sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore
		Transported Fill
6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic
		Native Soils/Sediment
8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
7, 8B, 8C		Sand, medium to coarse
7, 8B, 8C		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Sections B-B' and D-D'
North-South through Upper Metro Storm Drain Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-12

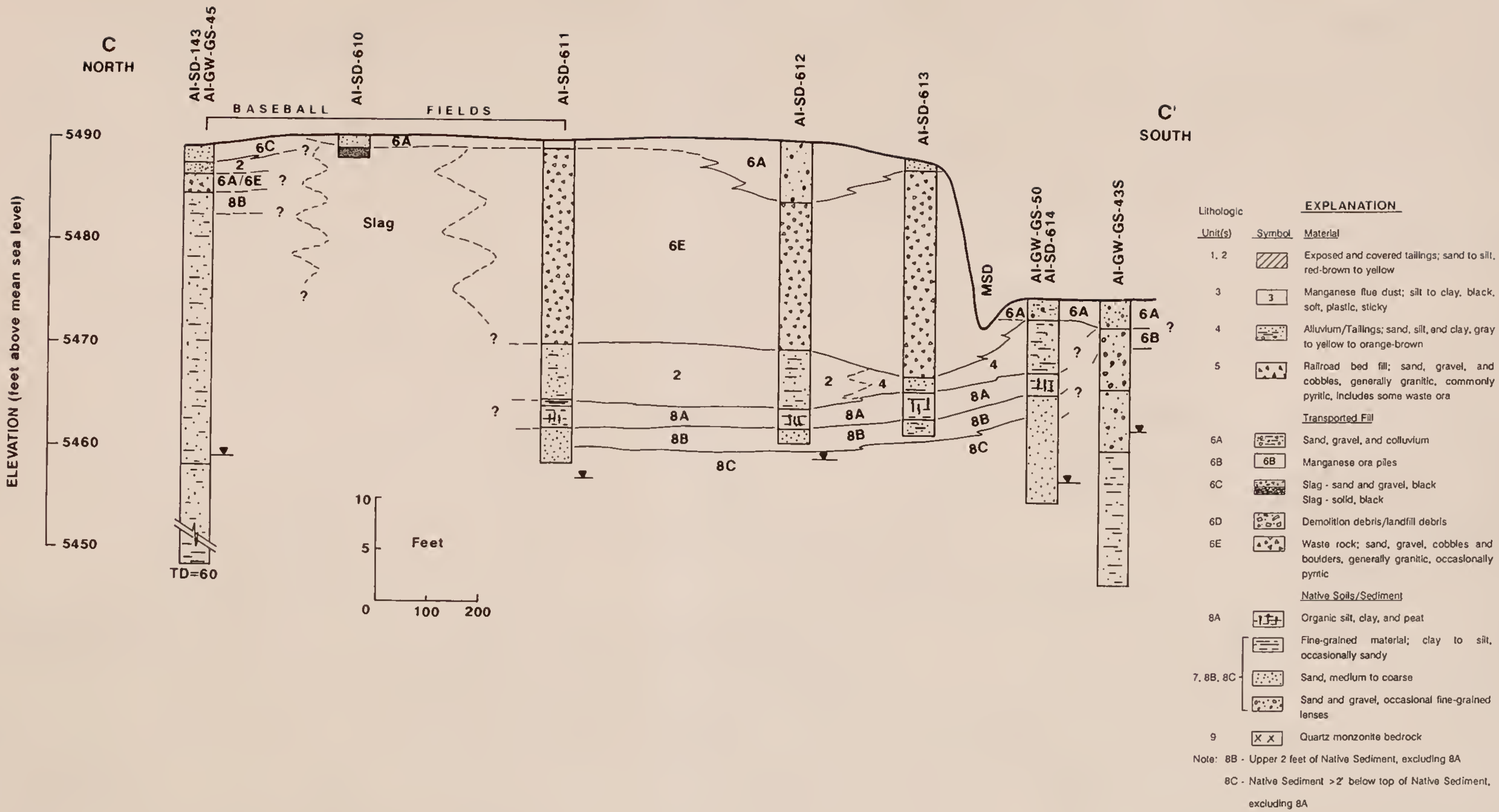
Geologic cross section C-C' (Figure 4-13) is located through the center of the upper Metro Storm Drain area and indicates that 20 feet of fill material overlies approximately six feet of tailings material near the center of the area. Fill material thickness decreases to approximately five feet at the north end of the section and three feet at the south end of the section. Approximately two feet of tailings material is present at the north end of the cross section and no tailings or fluvial/tailings deposits are present at the southern end of the section. A relatively large area consisting of solid slag material was not penetrable with the soil auger rig utilized for the investigation and the type of material underlying these deposits was not determined.

Geologic cross section D-D' (Figure 4-12) is located across the western portion of the upper Metro Storm Drain area. This cross section indicates that approximately seven to 14 feet of fill and tailings deposits overly native sands and gravel material. Tailings and fluvial alluvium/tailings material appear to be limited to the central portion of the section.

Isopach maps constructed for several types of fill and tailing deposits provide a general indication of the approximate thickness of the various material units encountered in the upper Metro Storm Drain area. Figure 4-14 is an isopach map of material unit 6A (transported fill, sand, and gravel colluvium). Material unit 6A generally is present at the surface and extends to various depths in the upper Metro Storm Drain area. Two relatively thick areas of unit 6A occur in the upper Metro Storm Drain area, one just east of the City/County Shop area and one adjacent to the Metro Storm Drain.

Figure 4-15 is an isopach map of material unit 6C (slag and slag sand and gravel) which occurs throughout the upper end of the operable unit. This unit appears to be thickest at the historic locations of the Parrott Smelter slag dumps (Figure 4-1), although only estimated thicknesses of the unit are possible due to the inability of several borings to penetrate the slag material at several locations.

Figure 4-16 in an isopach map of material unit 6E (transported waste rock). This unit appears to have been deposited around and over slag dumps and exposed tailings material and may represent emplaced waste rock derived from open pit operations. This material unit appears to be thickest in the City/County shop complex area.



Geologic Cross Section C-C'
North-South through Upper Metro Storm Drain Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-13

Isopach Map of Lithologic Unit 6A
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-14

— — Contour Interval 5 feet

o Material Sampling Location (thickness, feet)

• Soil Test Pit (thickness, feet)

NOTE:
Thickness information included only for sampling locations/test pits encountering lithologic unit mapped. Zero thickness indicated only for sampling locations/test pits penetrating native sediment (8B) without encountering lithologic unit mapped.

Isopach Map of Lithologic Unit 6C
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-15

Isopach Map of Lithologic Unit 6E
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-16

Figure 4-17 is an isopach map of tailings (unit 2) and fluvial sediments/tailings (unit 4) in the Metro Storm Drain area. These two units were combined for this map because the stratigraphic location and depositional origins of the materials are similar. The isopach map shows that tailings and fluvial alluvium/tailings deposits are thickest in the western half of the upper Metro Storm Drain area; a maximum thickness of 12 feet was identified in boring A1-SD-618 (Figure 4-17).

Figure 4-18 is an isopach map of material unit 8A (organic silt, clay and peat) in the upper Metro Storm Drain area. This material unit generally underlies tailings and fluvial alluvium/tailings material units and overlies native sediment. The isopach map indicates that the buried organic horizon is thickest along a linear trend that generally parallels the Metro Storm Drain.

Figure 4-19 is an isopach map showing thicknesses of material overlying tailings and/or fluvial sediments/tailings material units (Units 2, 4, and 8A). This isopach map was developed by combining thicknesses of all types of fill material overlying tailings materials. This map provides an indication of the locations and thicknesses of material which would have to be exhumed in order to expose buried tailings and mixed fluvial sediments and tailings material in the upper Metro Storm Drain area.

Isopach maps presented above were used to estimate volumes of various material units present in the upper Metro Storm Drain area. These calculated volumes are presented in Table 4-9. The estimated volume of covered tailings and mixed alluvium-tailings (units 2 and 4) in the upper Metro Storm Drain area is 190,000 cubic yards. The quantity of material overlying these units is about 840,000 cubic yards.

Two tailings material samples, (unit 2) one organic silt and clay (unit 8A) material sample, and one native sediment (unit 8C) material sample were analyzed for grain size distribution. Grain size data are contained in Appendix C-4. Tailings material samples (AI-SD-611-18 and AI-SD-619-425) are predominantly medium to fine sand with 11 to 14% fines (silt and clay). Under the Unified Soil Classification system, the tailings material would be classified as SW-SM and SM.

Isopach Map of Lithologic Units 2 and 4
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-17

Isopach Map of Lithologic Unit 8A
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-18

Isopach Map of Overburden
Overlying Lithologic Units 2, 4 and 8A
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-19

TABLE 4-9

VOLUME OF MATERIAL UNITS BY GEOGRAPHIC AREA;
TAILINGS/CONTAMINATED SOILS INVESTIGATION
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Geographic Area	Lithologic Unit(s)	Estimated Volume $(yd)^3$
Upper Metro Storm Drain	2 & 4	190,000
	6A	300,000
	6C	300,000
	6E	525,000
	8A	160,000
	Material overlying units 2 & 4	840,000
Lower Metro Storm Drain	2 & 4	200,000
	6D	570,000
Manganese Stockpile	2 & 4	430,000
	Material overlying unit 8B (2,3,4,6A,6C,8A)	1,630,000
Colorado Tailings	2 & 4	230,000
	Material overlying unit 8B (2,4,6A, 6C,8A)	580,000

A hydrometer analyses performed on sample AI-SD-611-18 indicates that the fine portion of the tailings material is comprised of approximately equal percentages of silt and clay. Grain size analysis results from sample AI-SD-612-13 (Appendix C-4) indicates that the organic silt and clay material unit (8A) is approximately 15% fine sand, 31% silt, and 54% clay size particles. Atterberg Limit testing was not performed on this sample, but it would likely be classified as a OL or OH in the Unified Soil Classification system.

Grain size analyses were also performed on material sample AI-AD-614-10, which is a sample of native material (unit 8C). This material was classified as a sand with silty sand and sandy silt lenses on the boring log and results of grain size analysis confirm the field classification of this material. This sample would be classified as a (SM) or silty sand under the Unified Soil Classification system.

4.3.2.2 Subsurface Chemistry

Total Metals

XRF analyses were performed on 194 material samples from the upper Metro Storm Drain area; laboratory total metals analyses were performed on 39 of these samples. XRF predicted metals concentration data for arsenic, chromium, copper, lead, zinc, and cadmium are contained in Appendix C-5; laboratory-determined metals data are contained in Appendix C-6.

Figure 4-20 illustrates XRF predicted concentrations and laboratory-determined concentrations of arsenic in buried tailings and mixed alluvium-tailings (material units 2 and 4) in the upper Metro Storm Drain area. Arsenic concentrations appear to be highest along the Metro Storm Drain in the southern portion of the area; laboratory determined concentrations range from a high of 3695 mg/kg in boring AI-SD-614 to a low of 150 mg/kg in boring AI-SD-147.

Figure 4-21 shows XRF predicted concentrations and laboratory concentrations of arsenic in material units 8A, 6C, and 6A. These units were combined to illustrate arsenic concentrations in material immediately overlying native sand, silt, and gravel material units. Arsenic concentrations in material units 8A, 6A, and 6C were generally lower than in

Arsenic Concentrations
in Lithologic Units 2 and 4
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-20

Arsenic Concentrations
in Lithologic Units 6A, 6C and 8A
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-21

overlying tailings and fluvial alluvium/tailings material. An exception to this relationship is at boring A1-SD-603, in which arsenic concentrations in material unit 8A (977 mg/kg) are higher than concentrations in unit 2 (183 mg/kg) (Figure 4-21).

Figure 4-22 shows arsenic concentrations in landfill/demolition debris (6D), which was encountered in borings AI-SD-141 and AI-SD-602 in the upper Metro Storm Drain area. Laboratory determined arsenic concentration was 78 mg/kg for landfill debris in boring AI-SD-141 and XRF predicted concentrations ranged from 69 mg/kg in boring AI-SD-141 to 384 mg/kg in boring AI-SD-602.

Figure 4-23 shows arsenic concentrations in the sand material present several feet below the base of the tailings in material unit 8B. Arsenic concentrations in unit 8B were lower than concentrations in overlying material units; laboratory concentrations in this unit ranged from a high of 254 mg/kg in boring AI-SD-612 to a low of 15 mg/kg in boring AI-SD-170.

Figure 4-24 shows XRF predicted concentrations and laboratory-determined concentrations of lead in material units 2 and 4 in the upper Metro Storm Drain area. Lead concentrations appear to be highest along the Metro Storm Drain in the southern portion of the upper Metro Storm Drain area; laboratory determined concentrations in these units ranged from a high of 3010 mg/kg in boring AI-SD-615 to a low of 133 mg/kg in boring AI-SD-603.

Figure 4-25 shows XRF predicted concentrations and laboratory concentrations of lead in material units 8A, 6C, and 6A. These units were combined to show lead concentrations of the material immediately overlying native sand, silt, and gravel material units. Lead concentration data for material units 8A, 6A, and 6C indicate overall lower concentrations than in overlying tailings and fluvial alluvium/tailings material, with the exception of boring A1-SD-603 in which lead concentrations in material unit 8A (231 mg/kg) were higher than concentrations measured in unit 2 (133 mg/kg).

Lead concentrations in material unit 6D are shown on Figure 4-26. Landfill debris from boring AI-SD-180 had a relatively high lead concentration of 8330 mg/kg.

Figure 4-27 shows lead concentrations in the upper two feet of native material (unit 8B) in the upper Metro Storm Drain area. Lead concentrations in unit 8B (ranging from 25 - 73 mg/kg) were measurably lower than concentrations in overlying fill and tailings material units.

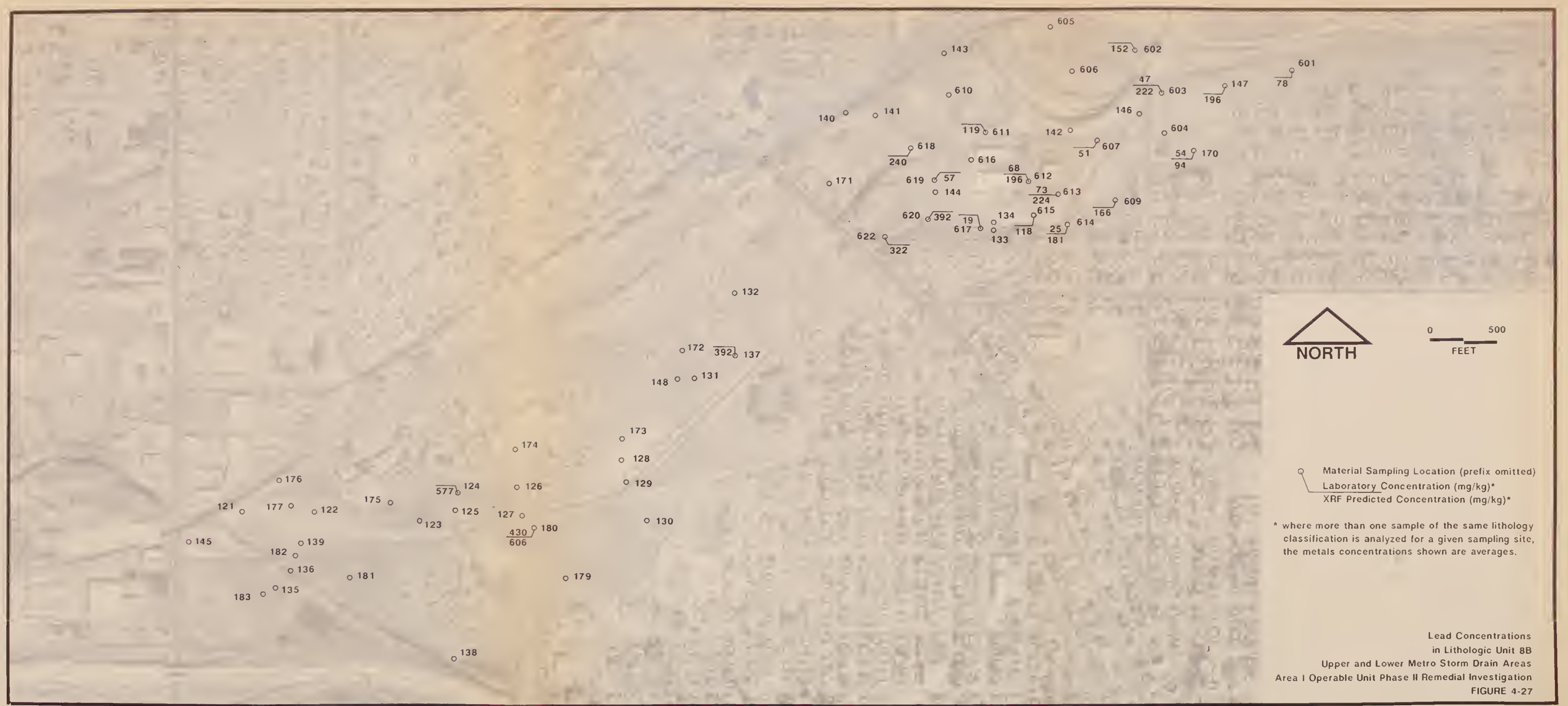
Arsenic Concentrations
in Lithologic Unit 6D
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-22

Arsenic Concentrations
in Lithologic Unit 8B
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-23

Lead Concentrations
in Lithologic Units 2 and 4
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-24

Lead Concentrations
in Lithologic Units 6A, 6C and 8A
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-25

Lead Concentrations
in Lithologic Unit 6D
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-26



Lead Concentrations
in Lithologic Unit 8B
Upper and Lower Metro Storm Drain Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-27

Table 4-10 statistically summarizes XRF and laboratory metals data by material unit in the upper Metro Storm Drain area. These data indicate the mixed alluvium-tailings material (unit 4) in the upper Metro Storm Drain area exhibited relatively higher laboratory-determined concentrations of arsenic (1239 mg/kg), copper (3564 mg/kg), lead (1039 mg/kg) and zinc (1992 mg/kg) than other material units in the area. The organic peat layer (unit 8A) underlying units 2 and 4 also exhibited relatively high metals concentrations. Transported fill material (unit 6) contained relatively lower average metals concentrations in the upper Metro Storm Drain area. The one sample of landfill material (unit 6D) analyzed by a laboratory contained relatively high concentrations of lead (2680 mg/kg) and zinc (22,400 mg/kg).

Metals by Grain Size

Total metals by grain size were determined for four material samples from the upper Metro Storm Drain area. Two of these samples represent material unit 2 and one sample was obtained each from each of material units 8A and 8C. Results of these analysis for selected metals are presented in Table 4-11. These data indicate that the -200 mesh material is almost always higher in metals concentration than the -80 to +200 size material for the tailings (unit 2), and native sand and gravel (unit 8C). Cadmium concentrations vary between grain sizes but are generally much lower than other metals. Organic silt and clay (unit 8A) metals concentrations, with the exception of zinc, did not vary significantly from the -200 fraction to the -80 to +200 size fraction. Rinseate water from material unit 8A contained higher concentrations of copper, zinc, and cadmium than rinseate water from tailings material samples, even though concentrations of these elements are similar in samples splits analyzed for total metals (Table 4-11).

Water Soluble Metals

Four samples obtained from the upper Metro Storm Drain area were analyzed for water soluble metals concentrations (Appendix C-8, Table 4-12). These samples represented covered tailings (unit 2), mixed alluvium-tailings (unit 4), slag material (unit 6C), and native soils greater than two feet below the base of units 2 and 4 (unit 8C). Data presented in Table 4-12 indicate mixed alluvium-tailings material (unit 4) liberates metals to water easily. Zinc in slag material in the upper Metro Storm Drain area also appears to readily solubilize in water.

E 4-10
STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
OR SUBSURFACE MATERIAL UNITS, UPPER METRO STORM DRAIN AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic		Cadmium		Chromium		Copper		Lead		Zinc	
		XRF	Lab	XRF	Lab	XRF	Lab	XRF	Lab	XRF	Lab	XRF	Lab
2	Covered tailings												
	Geometric Mean	< 352	295	< 4	< 1	< 22	< 1	< 465	358	< 400	551	< 584	808
	Arithmetic Mean	< 467	326	< 5	< 2	< 23	< 2	< 636	661	< 587	658	< 754	1098
	Standard Deviation	444	151	2	1	4	1	412	1092	417	377	573	888
	Maximum	2771	524	12	7	40	5	2071	3350	2732	1360	3500	2650
	Minimum	< 114	165	< 1	< 2	< 6	< 1	< 250	196	< 261	133	< 303	254
	Total No. of Samples	32	8	32	8	32	8	32	8	32	8	32	8
	No. Above Detection	30	8	27	5	14	4	27	8	21	8	29	8
4	Alluvium / Tailings												
	Geometric Mean	< 412	1239	< 4	< 5	< 26	< 7	2212	3564	< 723	1039	< 1290	1992
	Arithmetic Mean	< 1017	1853	< 6	< 9	< 28	< 14	6012	8511	< 1432	1555	< 1804	2742
	Standard Deviation	754	1595	8	6	11	16	10185	11669	1204	1233	1313	2362
	Maximum	4380	5040	47	21	69	53	40340	34000	6070	3040	4679	7560
	Minimum	< 120	148	< 2	< 2	< 11	< 3	330	252	< 363	221	< 396	465
	Total No. of Samples	22	7	22	7	22	7	22	7	22	7	22	7
	No. Above Detection	13	7	16	6	17	6	22	7	15	7	21	7
6A	Transported fill: Natural Alluvium												
	Geometric Mean	< 68	81	< 5	3	< 28	8	< 337	490	< 349	775	< 629	1016
	Arithmetic Mean	< 98	111	< 7	3	< 28	9	< 424	671	< 530	1032	< 1164	1174
	Standard Deviation	49	82	4	2	4	4	143	629	318	978	980	691
	Maximum	314	182	20	5	53	14	964	1590	2224	2480	3756	1970
	Minimum	< 288	23	< 3	2	< 22	5	< 299	173	< 288	351	< 273	527
	Total No. of Samples	19	4	19	4	19	4	19	4	19	4	19	4
	No. Above Detection	2	4	17	4	9	4	14	4	10	4	15	4
6C	Transported fill: Sand / gravel with slag												
	Geometric Mean	< 415	401	12	< 2	< 34	< 5	3159	2415	< 762	800	4183	6950
	Arithmetic Mean	< 518	471	15	< 2	< 35	< 7	5019	3051	< 887	994	7182	9023
	Standard Deviation	319	334	10	0	9	2	4296	2049	432	818	7084	5961
	Maximum	1527	851	32	4	53	11	12600	4890	1868	1930	19340	13000
	Minimum	< 288	228	4	< 4	< 17	< 8	570	842	< 348	418	652	2170
	Total No. of Samples	13	3	13	3	13	3	13	3	13	3	13	3
	No. Above Detection	11	3	13	1	12	2	13	3	12	3	13	3
6D	Transported fill: Demolition landfill												
	Geometric Mean	< 228	78	5	12	30	9	2861	863	< 349	2680	2023	22400
	Arithmetic Mean	< 260	78	5	12	30	9	6327	863	< 385	2680	2232	22400
	Standard Deviation	0	0	1	0	1	0	7980	0	0	0	1335	0
	Maximum	384	78	6	12	31	9	11970	863	548	2680	3176	22400
	Minimum	< 384	78	5	12	29	9	684	863	< 548	2680	1288	22400
	Total No. of Samples	2	1	2	1	2	1	2	1	2	1	2	1
	No. Above Detection	1	1	2	1	2	1	2	1	1	1	2	1

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

4-10

STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
OR SUBSURFACE MATERIAL UNITS, UPPER METRO STORM DRAIN AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
6E	Transported fill: Waste rock												
	Geometric Mean	< 40	45	< 4	< 0	< 24	5	497	252	< 151	141	< 285	40
	Arithmetic Mean	< 55	59	< 5	< 0	< 24	6	606	279	< 167	148	< 511	46
	Standard Deviation	46	45	3	0	0	2	587	124	33	53	812	30
	Maximum	406	113	13	0	28	7	2890	409	547	198	5473	90
	Minimum	< 64	20	< 2	< 0	< 24	4	257	112	< 280	85	< 253	19
	Total No. of Samples	26	4	26	4	26	4	26	4	26	4	26	4
	No. Above Detection	2	4	20	0	2	4	26	4	3	4	17	4
7	Native soils: Shallow; 0 - 1 in. depth												
	Geometric Mean	< 31	(4)	8	(4)	< 24	(4)	< 125	(4)	< 129	(4)	< 120	(4)
	Arithmetic Mean	< 32	(4)	8	(4)	< 24	(4)	< 125	(4)	< 129	(4)	< 120	(4)
	Standard Deviation	0	(4)	0	(4)	0	(4)	0	(4)	0	(4)	0	(4)
	Maximum	0	(4)	8	(4)	0	(4)	0	(4)	0	(4)	0	(4)
	Minimum	< 0	(4)	8	(4)	< 0	(4)	< 0	(4)	< 0	(4)	< 0	(4)
	Total No. of Samples	1		1		1		1		1		1	
	No. Above Detection	0		1		0		0		0		0	
8A	Native soils: Organic silts, clays, and peat												
	Geometric Mean	< 169	144	< 8	< 3	< 25	13	< 2354	2740	< 285	112	1230	1380
	Arithmetic Mean	< 257	593	< 10	< 8	< 25	14	< 5354	5017	< 382	149	1658	1581
	Standard Deviation	122	927	5	8	3	5	6895	6691	232	140	1193	1055
	Maximum	1292	2870	23	38	33	22	22140	21900	2395	499	4198	4370
	Minimum	< 294	12	< 3	< 1	< 18	6	< 359	953	< 344	35	214	719
	Total No. of Samples	20	10	20	10	20	10	20	10	20	10	20	10
	No. Above Detection	5	10	18	6	17	10	19	10	5	10	20	10
8B	Native soils: Sand, gravel, silt; upper 2 ft												
	Geometric Mean	< 56	39	< 5	< 1	< 25	13	< 678	332	< 173	50	< 493	295
	Arithmetic Mean	< 73	76	< 7	< 1	< 25	14	< 929	508	< 184	54	< 724	342
	Standard Deviation	52	102	4	0	1	5	884	458	45	19	362	154
	Maximum	0	254	16	2	30	19	4034	1220	392	73	1912	471
	Minimum	< 0	11	< 2	< 2	< 25	6	< 283	91	< 392	25	< 301	86
	Total No. of Samples	15	5	15	5	15	5	15	5	15	5	15	5
	No. Above Detection	0	5	13	1	6	5	14	5	1	5	11	5
8C	Native soils: Sand, gravel, silt; below 2 ft												
	Geometric Mean	< 47	17	< 5	< 1	< 25	11	< 415	303	< 162	51	< 345	324
	Arithmetic Mean	< 60	19	< 6	< 1	< 25	13	< 530	431	< 171	55	< 514	482
	Standard Deviation	45	7	3	0	1	7	298	350	42	23	343	481
	Maximum	94	32	15	2	30	28	1858	1000	334	106	2683	1650
	Minimum	< 94	7	< 2	< 1	< 22	5	< 258	79	< 260	27	< 266	102
	Total No. of Samples	39	10	39	10	39	10	39	10	39	10	39	10
	No. Above Detection	1	10	35	3	10	10	32	10	4	10	25	10

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

TABLE 4-11

SUMMARY OF TOTAL METALS AND TOTAL METALS BY GRAIN SIZE ANALYSES FOR SUBSURFACE SOILS/TAILINGS AND SIEVE RINSEATES AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

					CONCENTRATION-- mg/kg (soil) µg/l (water)							
SAMPLE NO.	AREA	DEPTH (feet)	LITHOLOGIC UNIT	MATERIAL	As	Cr	Cu	Pb	Zn	Cd	Wet Sieve %[3]	ASTM[4] Dupe Sieve
611-18	Upper Metro Storm Drain	22.0-25.3	2	Total[1]	165	<1	241	532	801	2	515.8 gm	
				-80 to +200	224	<1	231	654	3090	10	8.4%	--
				-200 mesh	1220	4	920	3320	3970	10	8.8%	--
				Rinseate[2]	800	13	1000	870	630	2		
612-13	Upper Metro Storm Drain	24.0-27.5	8D	Total	594	21	1050	95	1120	1	213.5 gm	
				-80 to +200	548	15	520	71	602	<1	3.9%	--
				-200 mesh	880	26	982	122	1120	<1	82.2%	--
				Rinseate	110	48	28000	8	18000	57		
614-10	Upper Metro Storm Drain	12.0-20.0	8C	Total	21.9	16.8	281	73.8	282	0.89	782.6 gm	
				-80 to +200	21.4	10.6	129	46.1	168	0.93	8.2%	--
				-200 mesh	46.1	20.8	444	120	413	0.51	44.2%	--
				Rinseate	3.0	8.0	980	2.9	590	12		
619-42S	Upper Metro Storm Drain	3.0-7.5	2	Total	363	2.1	429	821	1150	2.2	766.3 gm	
				-80 to +200	405	0.83	955	396	4300	13.8	8.1%	--
				-200 mesh	1980	5.10	2030	5170	3260	6.3	14.4%	--
				Rinseate	81.0	8.0	260	140	650	4.6		
117-02	Manganese Stockpile	1.0-10.0	3	Total	634	.92	269	1910	3380	10.1	553.8 gm	
				-80 to +200	531	.99	204	1340	2730	8.2	18.0%	--
				-200 mesh	763	1.0	263	1830	3110	5.9	75.7%	--
				Rinseate	12.1	8.0	6.0	11.9	120	1.0		
500-11	Manganese Stockpile	0.5-2.5	2	Total	293	<1	180	575	1550	4	746.5 gm	
				-80 to +200	215	<1	110	257	2150	6	16.0%	18.9%
				-200 mesh	1790	<1	1190	4890	9680	28	7.5%	9.6%
				Rinseate	970	<8	627	702	9460	26		

(1) Bulk soils/tailings sample analysis for total metals
(2) Deionized water used to perform modified wet sieve analysis
(3) Percent of total sample
(4) Duplicate sieve analysis using alternative ASTM C136 method

TABLE 4-11--continued

SUMMARY OF TOTAL METALS AND TOTAL METALS BY GRAIN SIZE ANALYSIS FOR SUBSURFACE SOILS/TAILINGS AND SIEVE RINSEATES AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

					CONCENTRATION-- mg/kg (soil) µg/l (water)							
SAMPLE NO.	AREA	DEPTH (feet)	LITHOLOGIC UNIT	MATERIAL	As	Cr	Cu	Pb	Zn	Cd	Wet Sieve %(3)	ASTM(4) Dupe Sieve
507-11	Manganese Stockpile	2.0-3.5	2	Total(1)	680	<1	626	2620	6220	16	713.0 gm	
				-80 to +200	581	1	372	1530	8070	22	15.3%	17.4%
				-200 mesh	2960	<1	2330	10700	17700	42	10.9%	13.2%
				Rinseate(2)	175	<8	797	150	20100	52		
508-02A	Manganese Stockpile	0.1-0.5	2	Total	283	<1	1680	585	2660	7	713.9 gm	--
				-80 to +200	123	2	220	161	260	1	42.6%	
				-200 mesh	1110	<1	1790	1570	3120	8	15.7%	
				Rinseate	2540	15	1880	1480	14000	31		
509-09	Manganese Stockpile	0.8-2.8	4	Total	2480	<1	21300	1850	49200	173	254.0 gm	
				-80 to +200	672	<1	1120	506	2100	8	4.2%	5.1%
				-200 mesh	3180	<1	27900	2470	53900	190	94.3%	91.6%
				Rinseate	66	27	200000	220	580000	5200		
516-10	Colorado Tailings	1.0-3.0	2	Total	588	1	312	268	1790	6	727.4 gm	
				-80 to +200	418	<1	446	241	5960	19	9.1%	--
				-200 mesh	2230	16	1400	2000	7530	22	10.6%	--
				Rinseate	660	10	590000	620	16000	78		
517-09	Colorado Tailings	1.0-2.5	2	Total	553	1	123	269	808	2	725 gm	
				-80 to +200	307	<1	65	168	1460	4	17.2%	17.6%
				-200 mesh	1620	2	371	1430	2440	7	23.8%	16.6%
				Rinseate	1100	10	5200	680	6100	23		
518-04	Colorado Tailings	1.5-2.5	8A	Total	114	14	3650	40	22700	113	332.3 gm	
				-80 to +200	104	10	5430	58	8110	101	4.2%	--
				-200 mesh	69	12	4480	67	25400	86	56.5%	--
				Rinseate	16	8	400	<1	14000	130		

(1) Bulk soils/tailings sample analysis for total metals
(2) Deionized water used to perform modified wet sieve analysis
(3) Percent of total sample
(4) Duplicate sieve analysis using alternative ASTM C136 method

TABLE 4-12

SUMMARY OF WATER SOLUBLE METALS FOR SUBSURFACE MATERIALS AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

LITHOLOGIC				CONCENTRATION (µg/L)					
AREA	SAMPLE NO.	UNIT	DEPTH (feet)	As	Cd	Cr	Cu	Pb	Zn
Upper Metro Storm Drain	134-03	4	1.3-2.5	260	290	81	820,000	<0.4	33,000
Upper Metro Storm Drain	606-09	6C	2.0-5.5	<3	73	<8	270	4.8	20,000
Upper Metro Storm Drain	611-18	2	22-25.3	140	1.8	<8	1,700	8	640
Upper Metro Storm Drain	614-10	8C	12-20	<3	6.3	<8	690	0.4	610
Upper Metro Storm Drain	GW-GS-50	8C	162-164	<3	0.49	<8	<6	<0.4	83
Upper Metro Storm Drain	GW-GS-50	8C	166-167	<3	0.83	<8	11	<0.4	70
Upper Metro Storm Drain	GW-GS-50	8C	168-176	<3	<0.1	<8	47	<0.4	120
Upper Metro Storm Drain	GW-GS-50	8C	242-244	29	<0.1	<8	<6	<0.4	28
Upper Metro Storm Drain	GW-GS-50	8C	244-248	44	<0.1	<8	<6	0.89	68
Upper Metro Storm Drain	GW-GS-50	8C	245	51	<0.1	<8	<6	<0.4	87
Upper Metro Storm Drain	GW-GS-50	8C	270	9.8	0.52	<8	<6	<0.4	18
Lower Metro Storm Drain	123-01	4	0-1.2	4.9	66	<8	660	<0.4	11,000
Lower Metro Storm Drain	173-04	4	1.7-2.4	5.3	0.72	<8	140	2.2	310
Lower Metro Storm Drain	175-02	7	0.2-1.5	12	0.86	<8	54	42	300
Lower Metro Storm Drain	182-05	8A	7.0-7.8	120	12	<8	32	<0.4	6,200
Manganese Stockpile	152-03	2	2.8-3.7	16	240	<8	520,000	2.0	100,000
Manganese Stockpile	507-11	2	2.0-3.5	24	40	18	300	10	14,000
Manganese Stockpile	506-11	4	6.0-9.5	18	180	14	6.0	800	23,000
Manganese Stockpile	509-09	4	0.8-2.8	23	4,100	25	330,000	15	740,000
Colorado Tailings	112-05	2	2.4-2.8	86	120	<8	170,000	5.4	39,000
Colorado Tailings	516-10	2	1.0-3.0	23	31	9	180,000	9.8	7,000
Colorado Tailings	518-04	8A	1.5-2.5	9.5	330	<8	100	0.9	22,000

Other water soluble metals analyses were completed on samples collected from monitoring well AI-GW-GS-50 in the upper Metro Storm Drain area. These data were collected to determine if a naturally mineralized lithologies were present at depths between 160 and 250 feet below ground surface which would serve as a natural contaminant source to groundwater present at these same depths. Water soluble data summarized in Table 4-12 suggest little potential of metals in sediments at these depths to solubilize.

4.3.3 Lower Metro Storm Drain Area

The lower Metro Storm Drain area includes the portion of the Area I Operable Unit from Harrison Avenue to Montana Street (Figure 4-2). This portion of the operable unit is characterized by both lowland swampy areas and filled areas; most of the land within this section of Area I is undeveloped.

4.3.3.1 Subsurface Lithology

Historic maps prepared by the U.S. Geological Survey (1898 and 1903 editions) show both Silver Bow Creek and Blacktail Creek with extensive marshy areas, particularly near the confluence of the two streams near Montana Street to about 2000 feet upstream. Construction of the Metro Storm Drain in 1930's appears to have been important in demarcating areas for subsequent dumping and demolition debris disposal in the lower Metro Storm Drain area. Most near surface material south of the Metro Storm Drain is demolition debris or landfill cover; material north of the Metro Storm Drain is largely mixed alluvium/tailings. Historic aerial photographs (Figure 4-1) show extensive areas of exposed tailings south of the Metro Storm Drain which are probably now covered by landfill deposits.

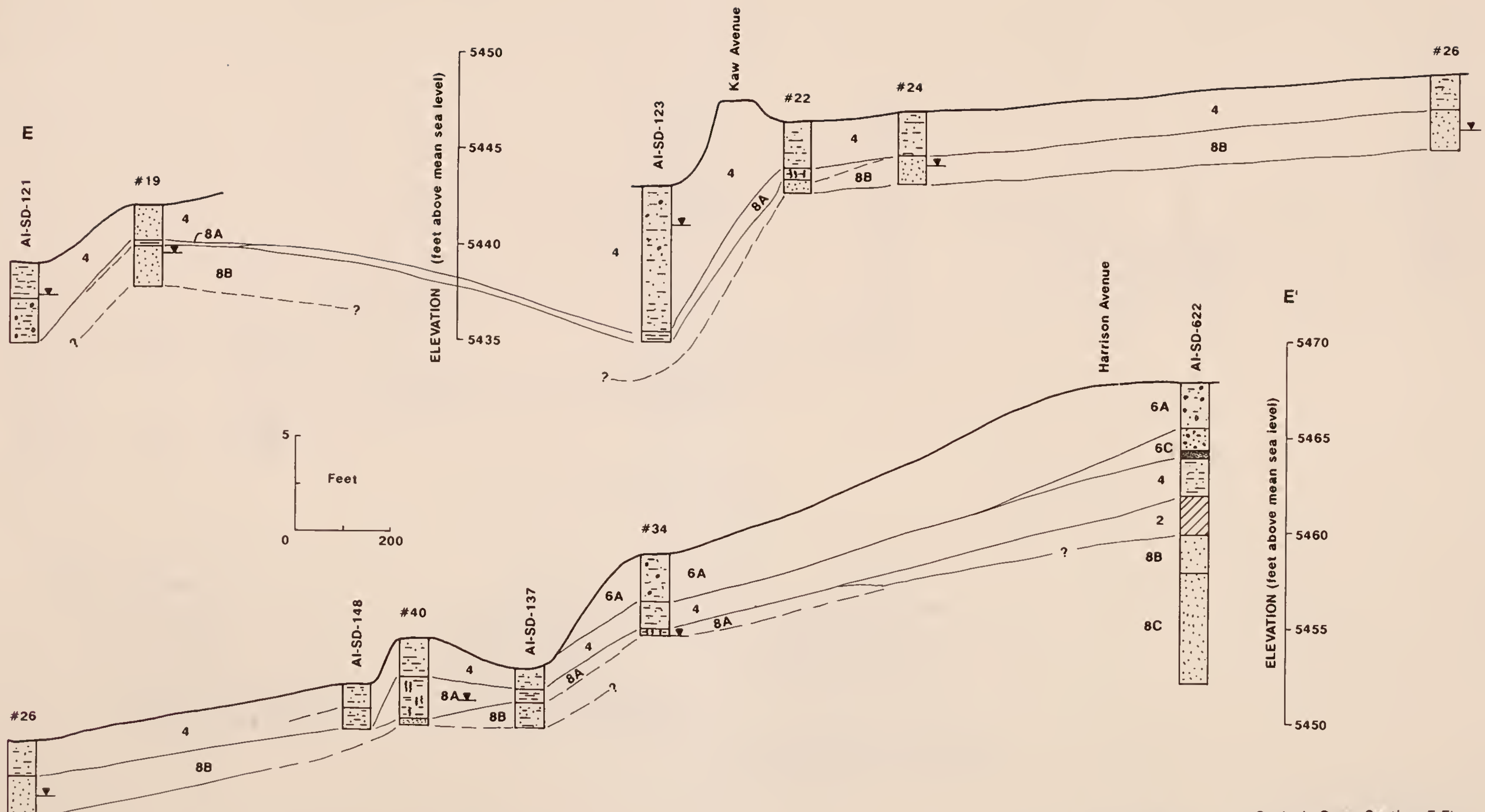
The area north of the Metro Storm Drain is generally comprised of mixed alluvium-tailings (unit 4), transported fill material (unit 6A), and fine grained native silts and clays (unit 7) (Table 4-5). Portions of unit 4 are unvegetated in areas north of the Metro Storm Drain. Material unit 6D (demolition and landfill debris) and unit 4 (mixed alluvium and tailings) make up most of the near surface material south of the Metro Storm Drain (Exhibit II).

The distribution of subsurface material units in the lower Metro Storm Drain area is depicted on six cross-sections (E-E' through J-J', Figure 4-10). Cross-section E-E' (Figure 4-28) shows the distribution of material units on the north side of the Metro Storm Drain. Elevations of soil borings were estimated from elevations of near-by surveyed monitoring wells in conjunction with a site topographic map. The thickness of mixed alluvium/tailings (unit 4) averages about two feet along the north side of the Metro Storm Drain with the exception of borings AI-SD-123, located just west of Kaw Avenue, and AI-SD-121, located east of Montana Street (Figure 4-28). Fill material (unit 6A) thins west of the Civic Center; virtually no fill is present proximal to the Metro Storm Drain from boring AI-SD-137 west (Figure 4-29).

Cross-section F-F' (Figure 4-29) is oriented east-west along the south side of the Metro Storm Drain. Most of this area appears to have been used as a landfill or as an area for disposal of demolition debris. Thicknesses of landfill cover and fill material in this area ranged from four to 11 feet; thickest deposits were identified near the KOA campground at boring AI-SD-181 (Figure 4-29). East of Blacktail Creek, landfill cover material generally overlies material unit 4 (mixed alluvium-tailings). West of Blacktail Creek, the landfill material grades into mixed tailings/alluvium near site AI-SD-145 (Figure 4-29).

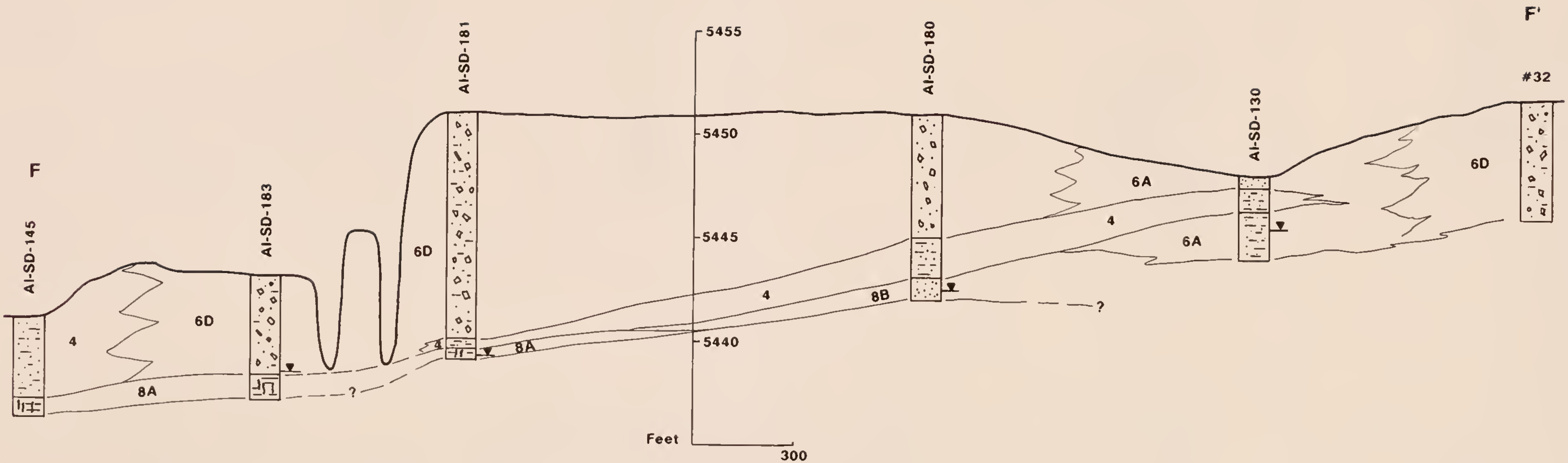
Four transverse cross sections across the lower Metro Storm Drain area and Blacktail Creek (Cross Sections G-G', H-H', I-I', and J-J', Figure 4-30) indicate a thinning of mixed tailings/alluvium (unit 4) northward and with increasing elevation away from the Metro Storm Drain. South of the Metro Storm Drain, cross sectional data indicates the historic use of this area as a landfill/dump area on top of mixed tailings and alluvium. In general, the tailings/alluvium unit (unit 4) is present in the lower Metro Storm Drain area as a 1.5- to 2-foot layer on buried native soil (unit 8); the unit is typically overlain by several feet of landfill/demolition debris (unit 6D).

Isopach maps of material units 4 (mixed alluvium and tailings) and 6D (demolition/landfill debris) in the lower Metro Storm Drain area are presented on Figures 4-17 and 4-19, respectively. Examination of Figure 4-17 indicates that the thickness of unit 4 material is relatively uniform over the lower Metro Storm Drain area. Thicknesses of material unit 6D are generally four to six feet where the unit is present in the lower Metro Storm Drain area.



NOTE:
See Fig. 4-29 for geologic explanation.

Geologic Cross Section E-E'
East-West through the Northern Part of the Lower Metro Storm Drain Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-28



EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore

Transported Fill

6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic

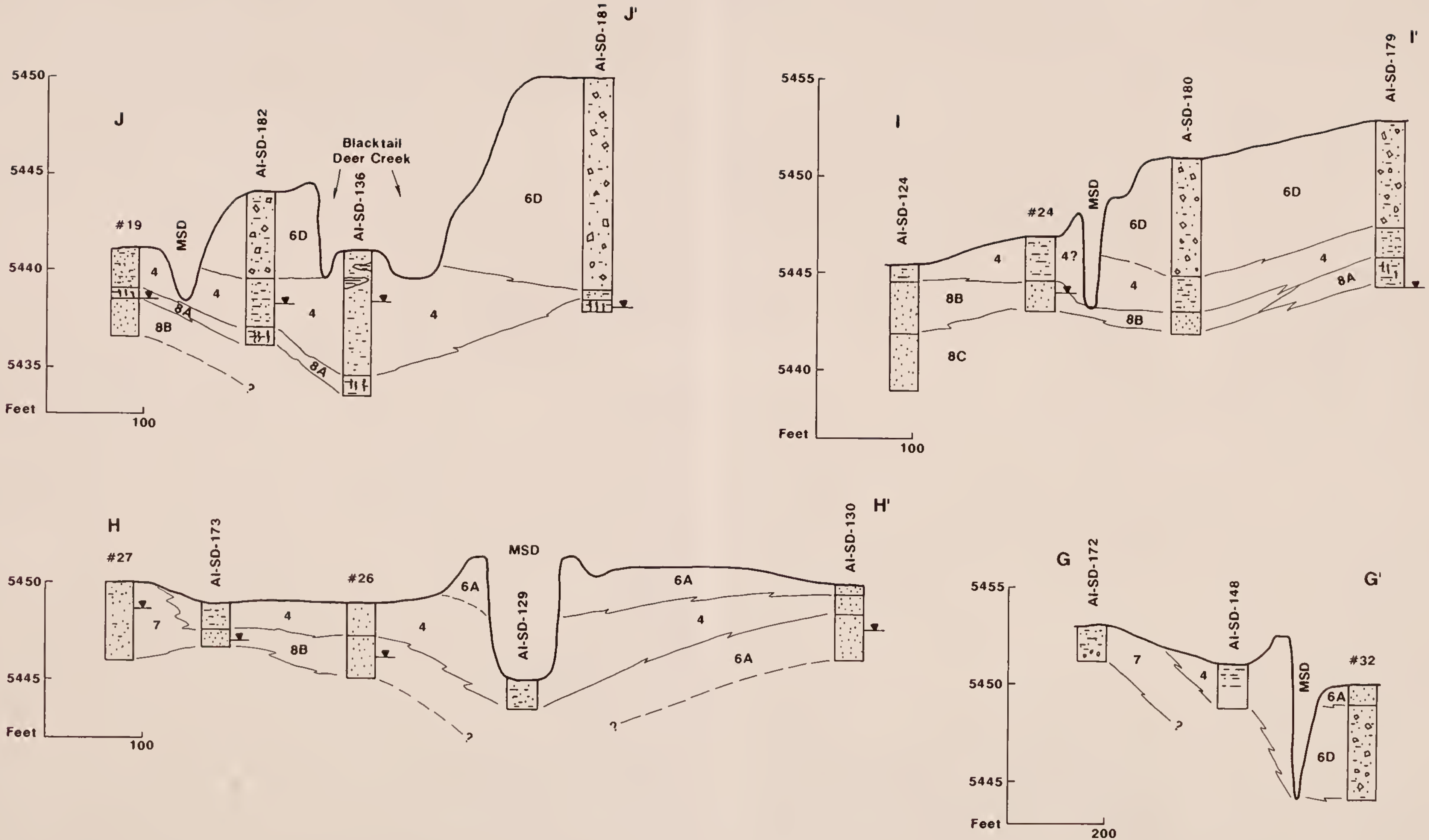
Native Soils/Sediment

8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Section F-F'
East-West through the Southern Portion of the Lower Metro Storm Drain Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-29



NOTE:
See Fig. 4-29 for geologic explanation.

Geologic Cross Sections G-G', H-H', I-I' and J-J'
North-South through Lower Metro Storm Drain Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-30

A relatively thick (approximately 11 feet) area of demolition debris appears to be located near the lower end of the Metro Storm Drain (Figure 4-19).

The approximate volume of covered tailings and mixed alluvium-tailings material in the lower Metro Storm Drain area is 200,000 cubic yards (Table 4-9). The total volume of demolition and landfill debris within Area I in the lower Metro Storm Drain area is approximately 570,000 cubic yards (Table 4-9).

4.3.3.2 Subsurface Chemistry

Total Metals

XRF analyses were performed on 94 samples obtained from the lower Metro Storm Drain area; total metals analyses were performed on 47 of these samples. XRF data are contained in Appendix C-5; laboratory metals data are contained in Appendix C-6.

Figure 4-20 shows XRF predicted concentrations and laboratory concentrations of arsenic in material units 2 and 4 in the lower Metro Storm Drain area. Arsenic concentrations appear to be highest at the upper end of the lower Metro Storm Drain area (1050 mg/kg at site AI-SD-137), in areas of exposed or poorly vegetated material (unit 4), and along the Metro Storm Drain (Figure 4-20).

Figure 4-22 shows arsenic concentrations in landfill material (unit 6D) south of the Metro Storm Drain. Arsenic concentrations in this material were generally lower than concentrations found in subjacent and adjacent mixed alluvium-tailings material (unit 4) ranging from 82 to 226 mg/kg.

Figure 4-24 shows XRF predicted concentrations and laboratory concentrations for lead in unit 4 (mixed alluvium and tailings) in the lower Metro Storm Drain area. Highest lead concentrations (about 800 mg/kg) generally occur in clay and silt units associated with the alluvial/tailings material. An exception to this trend appears to be site AI-SD-129, located on the south bank of the Metro Storm Drain below rip-rap material which had a lead concentration of 546 mg/kg (Figure 4-24). The material at this site was bright orange and

yellow, indicating a highly oxidizing environment that is repeatedly supplied with eroded material from upstream.

Figure 4-25 shows XRF predicted concentrations and laboratory concentrations for lead in material units 6A and 8A for the lower Metro Storm Drain area. Sample sites which exhibited relatively high arsenic concentrations also contained relatively high lead concentrations (600 - 1,000 mg/kg).

Figure 4-26 shows XRF predicted concentrations and laboratory concentrations for lead in unit 6D (demolition and landfill debris) which overlies unit 4 south of the Metro Storm Drain. Relatively high lead concentrations (8330 mg/kg and 1640 mg/kg) were measured in samples collected from unit 6D at sites AI-SD-180 and AI-SD-179 (Figure 4-26). Both of these samples were composites of material unit 6D from the surface to its contact with unit 4. The source of these relatively high lead concentrations is unknown but is suspected to be associated with dumped material in the area.

Table 4-13 is a statistical summary of XRF and laboratory-determined concentrations for arsenic, cadmium, chromium, copper, lead, and zinc for the various material units identified in the lower Metro Storm Drain area. These data indicate the mixed alluvium-tailings (material unit 4) exhibits relatively high concentrations of arsenic, cadmium, copper, lead, and zinc in comparison to other material units present in the lower Metro Storm Drain area. Metals concentrations decrease in the material unit underlying the mixed alluvium-tailings (unit 8A) and decrease again in the lithologic zone located greater than 2 feet below tailings or peat (unit 8C).

Relatively high arsenic concentrations were also measured in covered tailings material (unit 2) and in slag material (unit 6C) (Table 4-13). The one subsurface railway roadbed material sample analyzed contained relatively high concentrations of copper, lead, and zinc.

Metals by Grain Size

Samples obtained for metals by grain size analysis from the lower Metro Storm Drain area included two salt encrusted tailings-alluvium samples (173-01 and 177-01), one well vegetated tailings-alluvium sample (124-01) and one disturbed native subsoil (174-01) (Table

4-11). Samples 173-01 and 177-01 contained a high percentage of -200 mesh material (70.9% and 77.1% respectively) and relatively high total metals concentrations (Table 4-11).

Sample 124-01 (Table 4-11) was obtained from a well defined "A" horizon at a well vegetated site near the northern edge of the old Silver Bow Creek flood plain. Approximately 69% of this sample passed a 200 mesh sieve. Total metals concentrations in the finer fraction of this sample were also relatively higher than other samples analyzed (Table 4-11).

Sample 174-01 (Table 4-11) was obtained from a native subsoil of granitic sand. Slightly over 10% of the material passed the 200 mesh sieve; metals concentrations in this material were relatively low except for lead (787 mg/kg). Highest metals concentrations by grain size in the lower Metro Storm Drain area were generally associated with fine grained materials, particularly in material unit 4.

Water Soluble Metals

Nine samples were collected from the lower Metro Storm Drain area for analysis of water soluble metals (Table 4-12). These included seven tailings-alluvium samples (unit 4) and two native soil samples (unit 8). In general, the native soils, samples AI-SD-132-01 and AI-SD-174-01 contained relatively low concentrations of most soluble metals (Table 4-12). Five of the unit 4 samples were obtained from areas barren of vegetation (samples AI-SD-121-01, 125-01, 128-01, 131-01, and 173-01) (Table 4-12). These materials appeared to be located such that the material was subject to fluctuations in shallow groundwater. Water soluble metals concentrations in these materials were relatively high. Well vegetated unit 4 sample sites (AI-SD-126-01 and 145-01, Table 4-12) exhibited relatively low concentrations of water soluble metals except arsenic.

4.3.4 Manganese Stockpile Area

The manganese stockpile area includes the area between Montana Street and the Colorado Tailings (Figure 4-2). The Butte Reduction Works mill and smelter was formerly located in the eastern portion of this part of the Area I Operable Unit. Numerous slag walls were constructed in the area both north and south of modern-day Silver Bow Creek.

STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
OR SUBSURFACE MATERIAL UNITS, LOWER METRO STORM DRAIN AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
4	Alluvium / Tailings												
	Geometric Mean	< 200	362	14	< 5	< 26	< 5	1794	1757	< 537	468	2576	3262
	Arithmetic Mean	< 239	406	18	< 9	< 26	< 7	2405	2559	< 614	509	3412	4211
	Standard Deviation	60	211	11	8	5	4	1848	2303	177	236	2459	2923
	Maximum	615	818	44	28	38	15	7445	8560	1251	1020	9431	10500
	Minimum	< 278	207	2	< 1	< 19	< 2	347	303	< 452	241	432	958
	Total No. of Samples	26	11	26	11	26	11	26	11	26	11	26	11
	No. Above Detection	12	11	26	10	25	10	26	11	20	11	26	11
6A	Transported fill: Natural Alluvium												
	Geometric Mean	< 230	(4)	9	(4)	23	(4)	779	(4)	< 305	(4)	991	(4)
	Arithmetic Mean	< 240	(4)	9	(4)	24	(4)	919	(4)	< 365	(4)	1094	(4)
	Standard Deviation	6	(4)	3	(4)	1	(4)	541	(4)	0	(4)	563	(4)
	Maximum	285	(4)	14	(4)	25	(4)	1501	(4)	795	(4)	1874	(4)
	Minimum	< 270	(4)	7	(4)	22	(4)	317	(4)	< 795	(4)	529	(4)
	Total No. of Samples	4		4		4		4		4		4	
	No. Above Detection	3		4		4		4		1		4	
7	Native soils: Shallow; 0 - 1 in. depth												
	Geometric Mean	< 105	72	7	< 1	< 25	9	< 466	343	< 270	225	965	663
	Arithmetic Mean	< 171	90	8	< 2	< 25	12	< 572	501	< 308	285	1312	679
	Standard Deviation	47	56	6	1	0	10	262	421	43	249	1436	172
	Maximum	557	126	20	4	26	22	1140	931	551	573	4234	830
	Minimum	< 557	25	4	< 2	< 25	3	< 372	89	< 501	135	551	491
	Total No. of Samples	6	3	6	3	6	3	6	3	6	3	6	3
	No. Above Detection	1	3	6	2	4	3	5	3	2	3	6	3
8A	Native soils: Organic silts, clays, and peat												
	Geometric Mean	< 359	519	11	10	24	8	3433	3401	< 552	510	3715	3345
	Arithmetic Mean	< 550	803	12	10	24	10	5646	5229	< 707	615	4291	3698
	Standard Deviation	76	603	5	3	5	6	5008	4040	202	373	2705	1987
	Maximum	1103	1410	22	13	31	17	13030	8960	1447	1060	10160	7030
	Minimum	< 747	93	6	8	18	2	493	874	< 603	204	1657	1990
	Total No. of Samples	8	5	8	5	8	5	8	5	8	5	8	5
	No. Above Detection	4	5	8	5	8	5	8	5	5	5	8	5
8B	Native soils: Sand, gravel, silt; upper 2 ft												
	Geometric Mean	< 232	618	25	40	21	3	4766	6970	< 367	430	4267	4120
	Arithmetic Mean	< 267	618	27	41	21	3	5458	6970	< 414	430	4334	4120
	Standard Deviation	0	0	12	0	3	0	3761	0	0	0	1066	0
	Maximum	399	618	35	41	23	3	8117	6970	606	430	5087	4120
	Minimum	< 399	618	18	41	19	3	2798	6970	< 606	430	3580	4120
	Total No. of Samples	2	1	2	1	2	1	2	1	2	1	2	1
	No. Above Detection	1	1	2	1	2	1	2	1	1	1	2	1

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

4-13

STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
OR SUBSURFACE MATERIAL UNITS, LOWER METRO STORM DRAIN AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
8C	Native soils: Sand, gravel, silt; below 2 ft												
	Geometric Mean	< 135	(4)	13	(4)	31	(4)	719	(4)	< 517	(4)	2216	(4)
	Arithmetic Mean	< 135	(4)	13	(4)	31	(4)	747	(4)	< 584	(4)	2356	(4)
	Standard Deviation	0	(4)	2	(4)	5	(4)	228	(4)	157	(4)	1049	(4)
	Maximum	0	(4)	16	(4)	37	(4)	1019	(4)	946	(4)	3927	(4)
	Minimum	< 0	(4)	11	(4)	27	(4)	466	(4)	< 577	(4)	1772	(4)
	Total No. of Samples	4		4		4		4		4		4	
	No. Above Detection	0		4		4		4		3		4	

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

Several areas within the central portion of the manganese stockpile area are surrounded by slag walls and appear to have been filled with tailings material. Two identifiable tailing cells are located near the northwestern corner of this portion of the operable unit. These tailing cells were presumably repositories of waste materials derived through operation of the Butte Reduction Works Mill and Smelter. The western portion of the manganese stockpile area is presently occupied by an asphalt plant, a Butte/Silver Bow County gravel operation, and the Butte Sewage Treatment Plant.

4.3.4.1 Subsurface Lithology

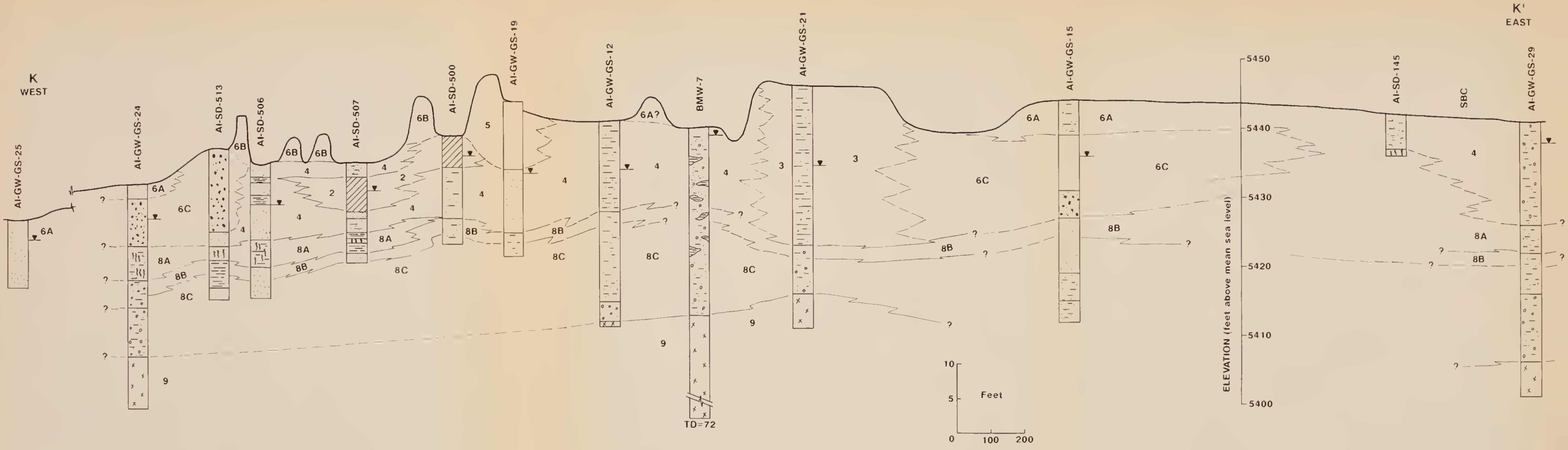
Subsurface material units encountered in the manganese stockpile area included covered tailings (unit 2), manganese flue dust (unit 3), alluvium/tailings (unit 4), railroad bed fill (unit 5), transported fill (units 6A, 6B, 6C, and 6E), and native soils/sediment (units 7, 8A, 8B, and 8C) (Table 4-5). Subsurface material units encountered at the site are depicted in a series of cross sections through the manganese stockpile area. Locations of these cross sections are shown on Figure 4-31.

Figure 4-32 is east-west geologic cross section K-K' which trends through the central portion of the manganese stockpile area. Figures 4-33 and 4-34 are north-south oriented geologic cross sections L-L', M-M', and N-N' through the east, central, and west portions of the manganese stockpile area, respectively.

Geologic cross sections through the manganese stockpile area generally indicate that the area has been filled with a heterogeneous assortment of materials. Geologic cross sections K-K', L-L', and M-M' indicate that the eastern portion of the manganese stockpile area has been filled predominantly with sand, gravel, and colluvium (unit 6A), loose slag material (unit 6C), and alluvium/tailings (unit 4) (Table 4-5). Geologic cross sections K-K' and N-N' indicate that the central portion of the area has been filled predominantly with tailings (unit 2) and alluvium/tailings (unit 4). Geologic cross-section K-K' (Figure 4-32) indicates that the western portion of the area contains some slag transported fill (unit 6C) along with some sand, gravel, and colluvium transported fill (unit 6A).

A deposit of manganese flue dust (unit 3) is present in a localized, triangular shaped area in the southeastern portion of the manganese stockpile area (Exhibit II). Monitoring well

Locations of Geologic Cross Sections
Manganese Stockpile, Colorado Tailings,
West of Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-31



Lithologic

EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings, sand to silt, red-brown to yellow
3	3	Manganese flue dust, silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore

Transported Fill

6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic

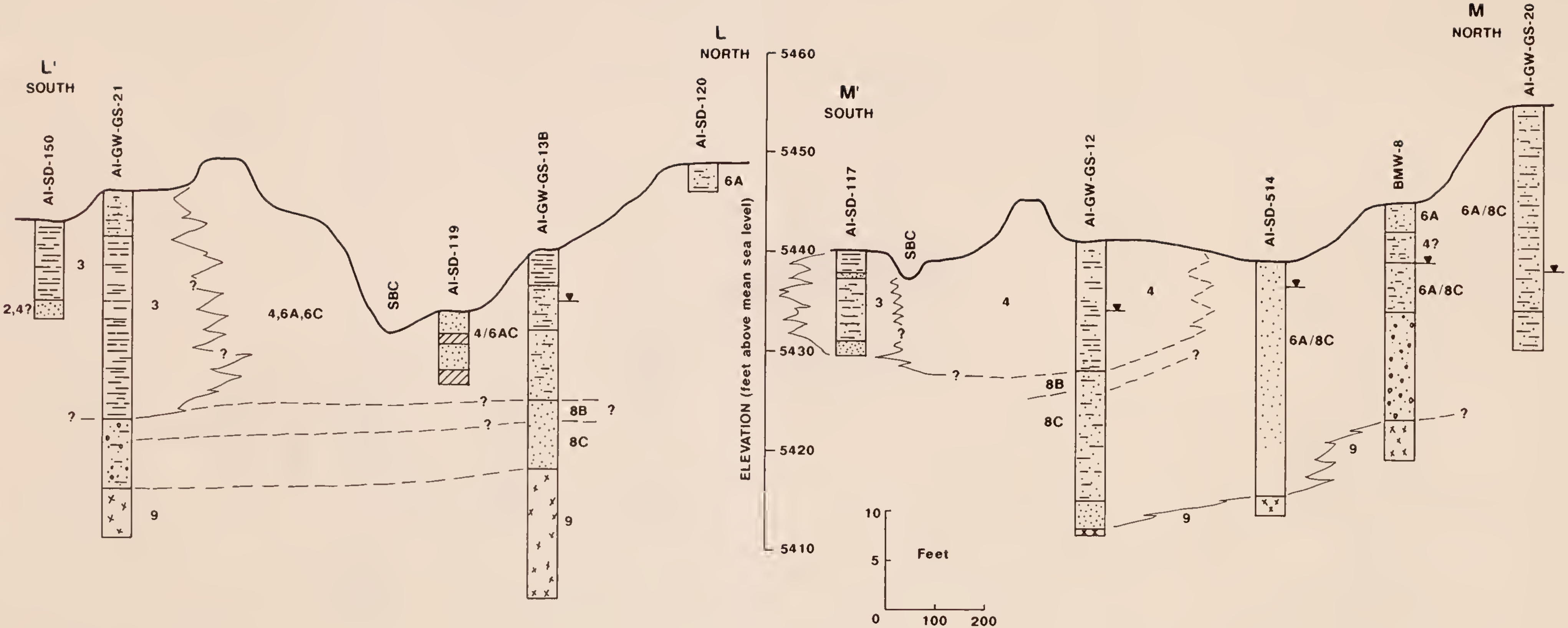
Native Soils/Sediment

8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Section K-K'
East West through Manganese Stockpile Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-32



EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore

Transported Fill

6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic

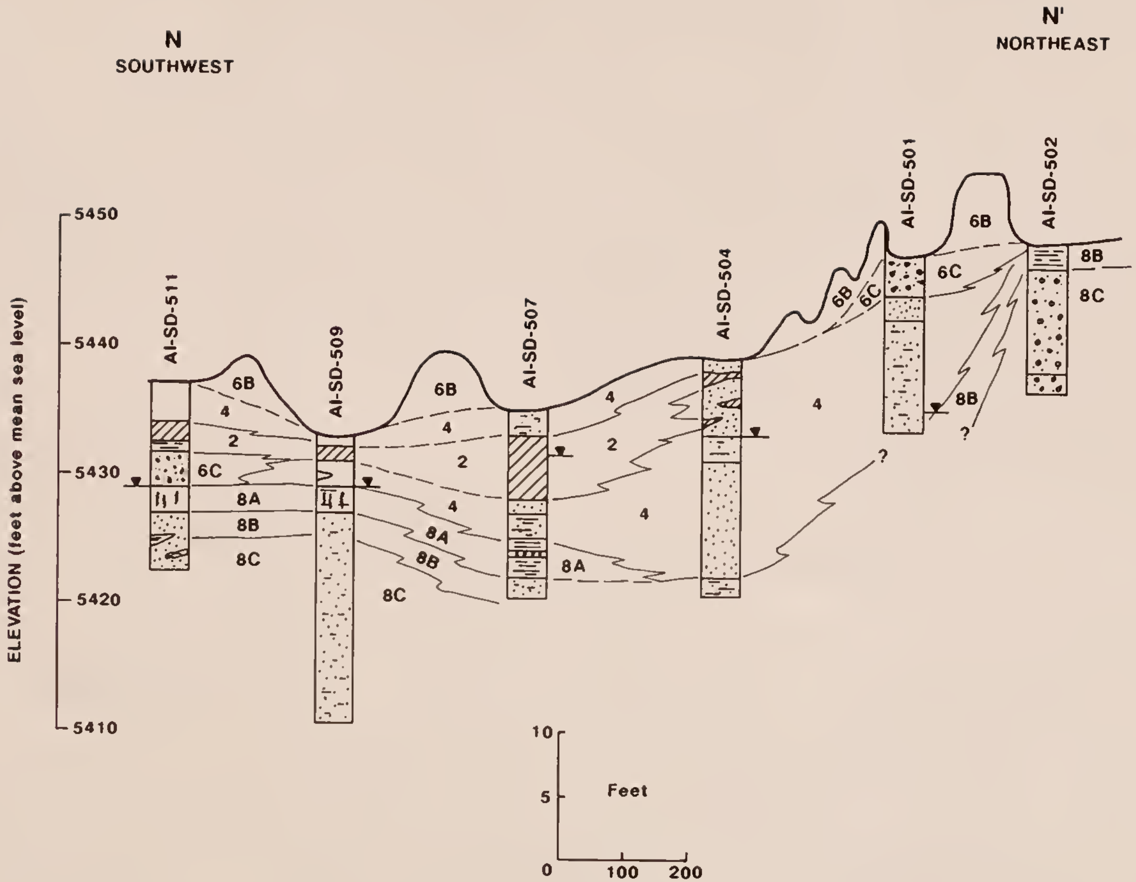
Native Soils/Sediment

8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Sections L-L' and M-M'
North-South through Manganese Stockpile Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-33



EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore
		Transported Fill
6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic
		Native Soils/Sediment
8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Section N-N'
Southwest-Northeast through Manganese Stockpile Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-34

boring AI-GW-GS-21 encountered 23 feet of manganese flue dust in the central portion of this area and soil borings AI-SD-117 and AI-SD-150 encountered nine and eight feet of manganese flue dust, respectively. The lateral distribution of this manganese flue dust appears to be confined to a specific area; there is no evidence of this type of material elsewhere in Area I.

Isopach maps constructed for combined material units 2 (covered tailings) and 4 (alluvium-tailings) and for all overburden overlying material unit 8B (upper 2 feet of native material) in the manganese stockpile area are presented in Figures 4-35 and 4-36 respectively. Figure 4-35 indicates that the thickest deposits of tailings and alluvium-tailing deposits occur in the central portion of the manganese stockpile area. A maximum combined thickness of 17 feet for these two material units was encountered in boring A1-SD-504 (Figure 4-35).

The isopach map depicted on Figure 4-36 indicates that central the portion of the manganese stockpile area appears to contain the thickest deposits of transported fill, tailings, and other deposits overlying unit 8B. Thicknesses of these deposits appear to decrease to the north and south. Thicknesses of fill in the manganese stockpile area range from 0 to 24 feet thick.

Grain size analyses were performed on four subsurface samples collected from the manganese stockpile area. Grain size data are presented in Appendix C-4. Three grain size analyses were performed on covered tailings samples (samples AI-SD-500-11, 507-11, and 508-02A) and one analysis was completed on a mixed alluvium-tailings sample (sample AI-SD-509-09).

Covered tailings samples (unit 2) contained 12-16% fines and are classified as well graded sand with silt (SW-SM) and silty sand (SM) according to the Unified Soil Classification system. The sample of alluvium-tailings (unit 4) contained 93% fines (70% silt and 23% clay) and is classified as a low plastic silt (ML).

Volume estimates for combined material units 2 and 4 and of all material units overlying material unit 8B in the manganese stockpile area are contained in Table 4-9. The estimated volume of tailings and mixed alluvium-tailings in the manganese stockpile area is 430,000 cubic yards. The majority of this material is located in the central portion of the area. The

Isopach Map of Lithologic Units 2 and 4
Manganese Stockpile, Colorado Tailings,
West of Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-35

Isopach Map of Overburden
Overlying Lithologic Unit 8B
Manganese Stockpile, Colorado Tailings,
West of Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-36

estimated volume of material overlying material unit 8B (native material) in the manganese stockpile area is 1.63 million cubic yards (Table 4-9).

4.3.4.2 Subsurface Chemistry

Total Metals

XRF analyses were performed on 171 subsurface material samples from the manganese stockpile area. Total metals analyses were performed on 67 material samples and five subsurface material samples were analyzed for total metals by grain size. Water soluble metals analyses were performed on four material samples from the area. Appendix C-5 contains XRF predicted concentration data for material samples. Appendix C-6 contains CLP laboratory determined total metals concentrations. Metals by grain size data and water soluble metals data are contained in Appendices C-7 and C-8, respectively.

Table 4-14 is a statistical summary of XRF predicted and laboratory determined concentrations of arsenic, cadmium, chromium, copper, lead, and zinc by subsurface material units in the manganese stockpile area. Average laboratory concentrations of arsenic in material units 2, 4, 6C, and 8A are relatively consistent, ranging from 488 mg/kg to 1,074 mg/kg. Laboratory arsenic concentrations in two samples of manganese flue dust are slightly lower with an average concentration of 635 mg/kg. Arsenic concentrations in native soil materials drop off dramatically with laboratory concentrations averaging 27 mg/kg for material unit 8C (Table 4-14).

The areal distribution of laboratory determined concentrations and XRF predicted concentrations for arsenic in material units 2 and 4, 6A, 6C, and 8A, and 8B are presented in Figures 4-37, 4-38. and 4-39, respectively. There does not appear to be any identifiable trend to arsenic occurrence spatially in the manganese stockpile area.

Average laboratory determined lead concentrations in the manganese stockpile area range from a high of 3,914 mg/kg in material unit 4 (alluvium-tailings) to a low of 116 mg/kg in material unit 8C (native sand and gravel) (Table 4-14). Two samples of material unit 3 (manganese flue dust) exhibited an average lead concentration of 2,700 mg/kg. Covered tailings (material unit 2) had an average lead concentration of 838 mg/kg. The organic

STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
FOR SUBSURFACE MATERIAL UNITS, MANGANESE STOCKPILE AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
2	Covered tailings												
	Geometric Mean	< 579	542	12	9	< 19	< 1	< 1209	1095	< 1031	877	1789	2740
	Arithmetic Mean	< 810	1119	15	11	< 23	< 4	< 3485	4826	< 1392	1213	2636	3857
	Standard Deviation	442	1092	11	7	12	3	6117	7802	736	807	2372	2806
	Maximum	1913	3180	37	22	45	13	25600	22200	2964	2620	9422	7880
	Minimum	< 310	12	3	3	< 6	< 1	< 351	36	< 476	87	362	458
	Total No. of Samples	16	8	16	8	16	7	16	8	16	8	16	8
	No. Above Detection	14	8	16	8	13	3	14	8	14	8	16	8
3	Manganese flue dust												
	Geometric Mean	< 291	2070	11	10	< 6	3	< 153	10500	< 674	1220	2909	4120
	Arithmetic Mean	< 433	2070	11	10	< 8	3	< 1613	10500	< 766	1220	3360	4120
	Standard Deviation	324	0	3	0	4	0	1753	0	357	0	1286	0
	Maximum	1705	2070	14	10	18	3	12630	10500	1773	1220	4576	4120
	Minimum	< 279	2070	6	10	< 5	3	< 1477	10500	< 511	1220	471	4120
	Total No. of Samples	9	1	9	1	9	1	9	1	9	1	9	1
	No. Above Detection	5	1	9	1	7	1	2	1	8	1	9	1
4	Alluvium / Tailings												
	Geometric Mean	< 451	< 504	29	24	< 39	< 1	< 2250	3285	2815	3844	7518	15237
	Arithmetic Mean	< 702	< 1304	46	63	< 55	< 2	< 6417	8104	3646	13259	14938	20693
	Standard Deviation	501	1330	49	80	37	0	9850	9053	2514	38518	18556	15770
	Maximum	2828	3850	223	270	149	17	44930	24100	9548	167000	83900	51800
	Minimum	< 270	< 90	3	3	< 4	< 17	< 268	428	526	834	618	3890
	Total No. of Samples	43	18	43	18	43	10	43	18	43	18	43	18
	No. Above Detection	31	17	43	18	42	1	40	18	43	18	43	18
6A	Transported fill: Natural Alluvium												
	Geometric Mean	< 135	89	7	1	28	3	< 279	242	< 320	324	769	706
	Arithmetic Mean	< 135	89	8	1	28	3	< 481	242	< 370	324	863	706
	Standard Deviation	0	0	4	0	2	0	313	0	0	0	532	0
	Maximum	0	89	12	1	30	3	1024	242	665	324	1476	706
	Minimum	< 0	89	4	1	26	3	< 360	242	< 665	324	519	706
	Total No. of Samples	3	1	3	1	3	1	3	1	3	1	3	1
	No. Above Detection	0	1	3	1	3	1	2	1	1	1	3	1
6C	Transported fill: Sand / gravel with slag												
	Geometric Mean	< 576	213	44	18	< 23	< 0	< 6564	5040	1709	2470	12003	26500
	Arithmetic Mean	< 809	213	52	18	< 29	< 0	<12586	5040	1867	2470	14965	26500
	Standard Deviation	551	0	32	0	11	0	12397	0	827	0	9582	0
	Maximum	2085	213	106	18	50	0	46380	5040	3658	2470	32880	26500
	Minimum	< 357	213	15	18	< 11	< 0	< 4154	5040	851	2470	3293	26500
	Total No. of Samples	12	1	12	1	12	1	12	1	12	1	12	1
	No. Above Detection	10	1	12	1	11	0	11	1	12	1	12	1

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

LE 4-14

STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
FOR SUBSURFACE MATERIAL UNITS, MANGANESE STOCKPILE AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/02/90

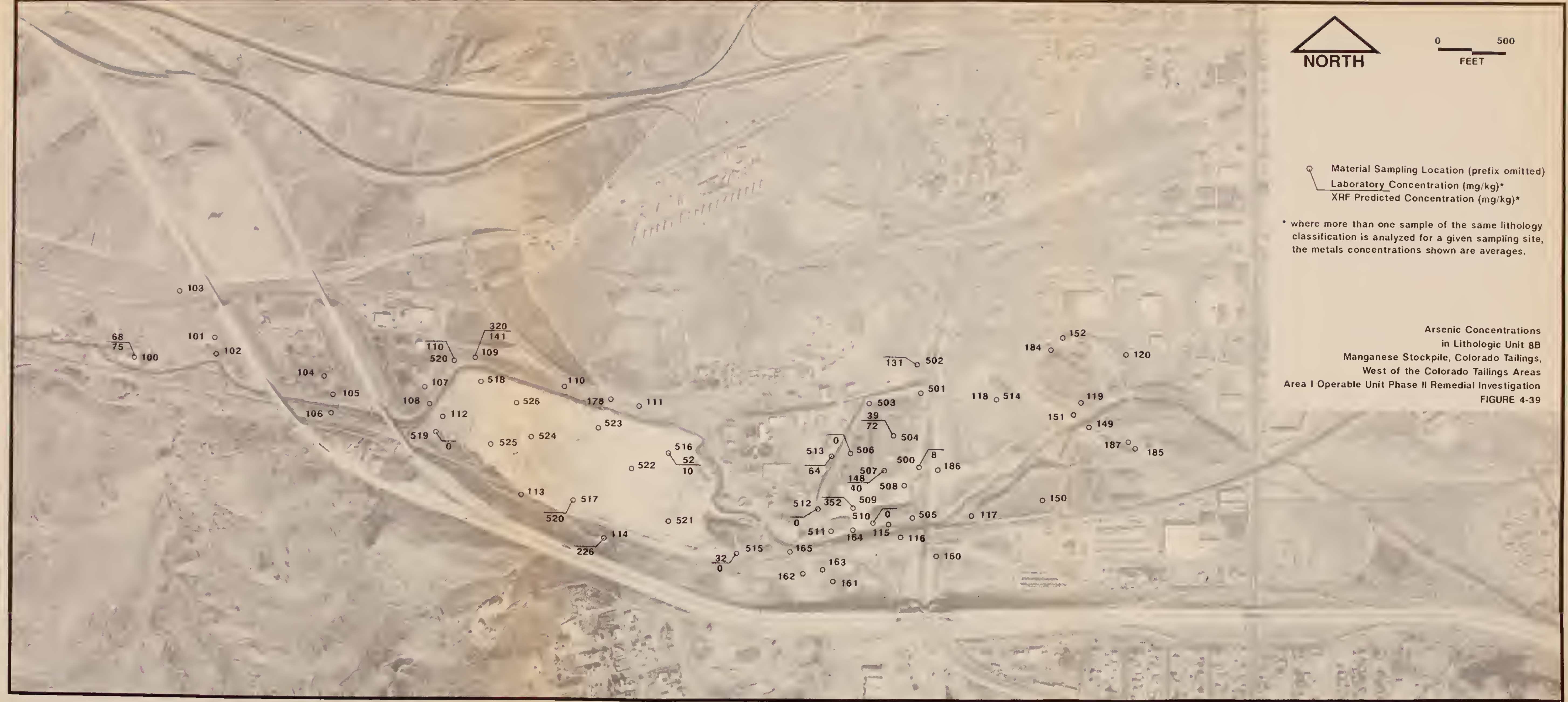
Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
8A	Native soils: Organic silts, clays, and peat												
	Geometric Mean	< 175	115	25	10	< 37	< 8	< 1862	444	< 1089	454	5244	4499
	Arithmetic Mean	< 344	926	32	21	< 153	< 13	< 5279	4410	< 1399	590	7629	7680
	Standard Deviation	223	1959	24	30	341	3	6661	9442	822	352	5907	8090
	Maximum	1915	4430	88	65	1234	19	24040	21300	3073	924	16820	20100
	Minimum	< 545	32	8	2	< 20	< 12	< 273	78	< 477	95	1002	1090
	Total No. of Samples	10	5	10	4	10	5	10	5	10	5	10	5
	No. Above Detection	2	5	10	4	8	4	9	5	9	5	10	5
8B	Native soils: Sand, gravel, silt; upper 2 ft												
	Geometric Mean	< 141	76	< 10	5	< 25	8	< 1176	227	< 353	678	< 1264	2068
	Arithmetic Mean	< 168	93	< 14	5	< 25	9	< 2065	437	< 419	944	< 1910	2155
	Standard Deviation	39	77	8	0	3	6	1879	528	78	928	1454	856
	Maximum	386	148	37	5	30	14	5738	811	774	1600	5746	2760
	Minimum	< 317	39	< 6	5	< 21	5	< 385	64	< 514	287	< 398	1550
	Total No. of Samples	10	2	10	1	10	2	10	2	10	2	10	2
	No. Above Detection	2	2	9	1	9	2	9	2	5	2	9	2
8C	Native soils: Sand, gravel, silt; below 2 ft												
	Geometric Mean	< 61	23	8	< 4	< 23	< 3	< 311	149	< 207	127	< 602	1213
	Arithmetic Mean	< 86	131	9	< 8	< 23	< 6	< 695	1641	< 228	231	< 874	1566
	Standard Deviation	49	292	5	3	1	5	580	2902	70	260	755	1280
	Maximum	333	727	24	13	25	15	3745	7200	607	745	3336	4000
	Minimum	< 333	7	3	< 6	< 20	< 1	< 242	21	< 305	10	< 258	432
	Total No. of Samples	19	6	19	4	19	6	19	6	19	6	19	6
	No. Above Detection	1	6	19	3	8	5	9	6	5	6	17	6

NOTES: 1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

Arsenic Concentrations
in Lithologic Units 2 and 4
Manganese Stockpile, Colorado Tailings,
West of the Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-37

Arsenic Concentrations
in Lithologic Units 6A, 6C and 8A
Manganese Stockpile, Colorado Tailings,
West of the Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-38



Arsenic Concentrations
in Lithologic Unit 8B
Manganese Stockpile, Colorado Tailings,
West of the Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-39

zone (unit 8A) in the manganese stockpile area contains slightly lower lead concentrations (454 mg/kg).

Figures 4-40, 4-41, and 4-42 contain XRF predicted values and laboratory determined concentrations of lead in material units 2 and 4, 6A, 6C, and 8A, and 8B, respectively. Highest lead concentrations in material units 2 and 4 (Figure 4-40) appear to be concentrated in the central impoundment area. Lead concentrations in material units 6A. 6C, and 8A (Figure 4-41) are variable throughout the site as are limited lead data for material unit 8B (Figure 4-42).

Statistical summaries of XRF predicted concentrations and laboratory concentrations of cadmium, chromium, copper, and zinc are also contained in Table 4-12. Average laboratory concentrations of cadmium are highest at 25 mg/kg in material unit 4 (tailings-alluvium) and lowest in material unit 6A at 1 mg/kg. Average laboratory concentrations of chromium are highest in material units 6A and 8A at 8 mg/kg and lowest in material units 2, 4, 5, and 6C at 1 mg/kg.

In general, average laboratory concentrations of copper and zinc are highest in material units 2, 4, 6A, 6C, and 8A and lowest in material units 8B and 8C. Average laboratory concentrations of copper range from a high of 3,120 mg/kg in alluvium/tailings (unit 4) and a low of 206 mg/kg in native sediment (unit 8C). Average laboratory concentrations of zinc range from a high of 15,389 mg/kg in material unit 4 and a low of 877 mg/kg in material unit 6A. Manganese flue dust (unit 3) appears to have very low concentrations of copper and relatively high concentrations of zinc and lead.

Metals by Grain Size

Five subsurface material samples were collected within the manganese stockpile area for analysis of total metals by grain size. Material units analyzed included three samples of covered tailings (unit 2), one sample of manganese flue dust (unit 3), and one sample of alluvium/tailings (unit 4). Appendix C-6 contains the total metals by grain size data base.

Table 4-11 contains resultant laboratory concentrations for selected metals of the -80 to +200 mesh material, -200 mesh material, rinseate water used to wash the sample through

Lead Concentrations
in Lithologic Units 2 and 4
Manganese Stockpile, Colorado Tailings,
West of the Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-40

Lead Concentrations
in Lithologic Units 6A, 6C and 8A
Manganese Stockpile, Colorado Tailings,
West of the Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-41

Lead Concentrations in Lithologic Unit 8B
Manganese Stockpile, Colorado Tailings,
West of the Colorado Tailings Areas
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-42

the sieves, and total metals concentrations for sample splits using the entire sample. Concentrations of arsenic, cadmium, chromium, copper, lead, and zinc in the -200 sieve fraction were generally two to 10 times higher than concentrations in the -80 to +200 size fraction. Concentrations of metals in the entire sample were slightly higher than concentrations in the -80 to +200 size fraction. Metals concentration in rinseate water varies considerably from sample to sample. Concentrations range from less than 1% to over 80%, with no apparent relationship to material lithology or grain size.

Water Soluble Metals

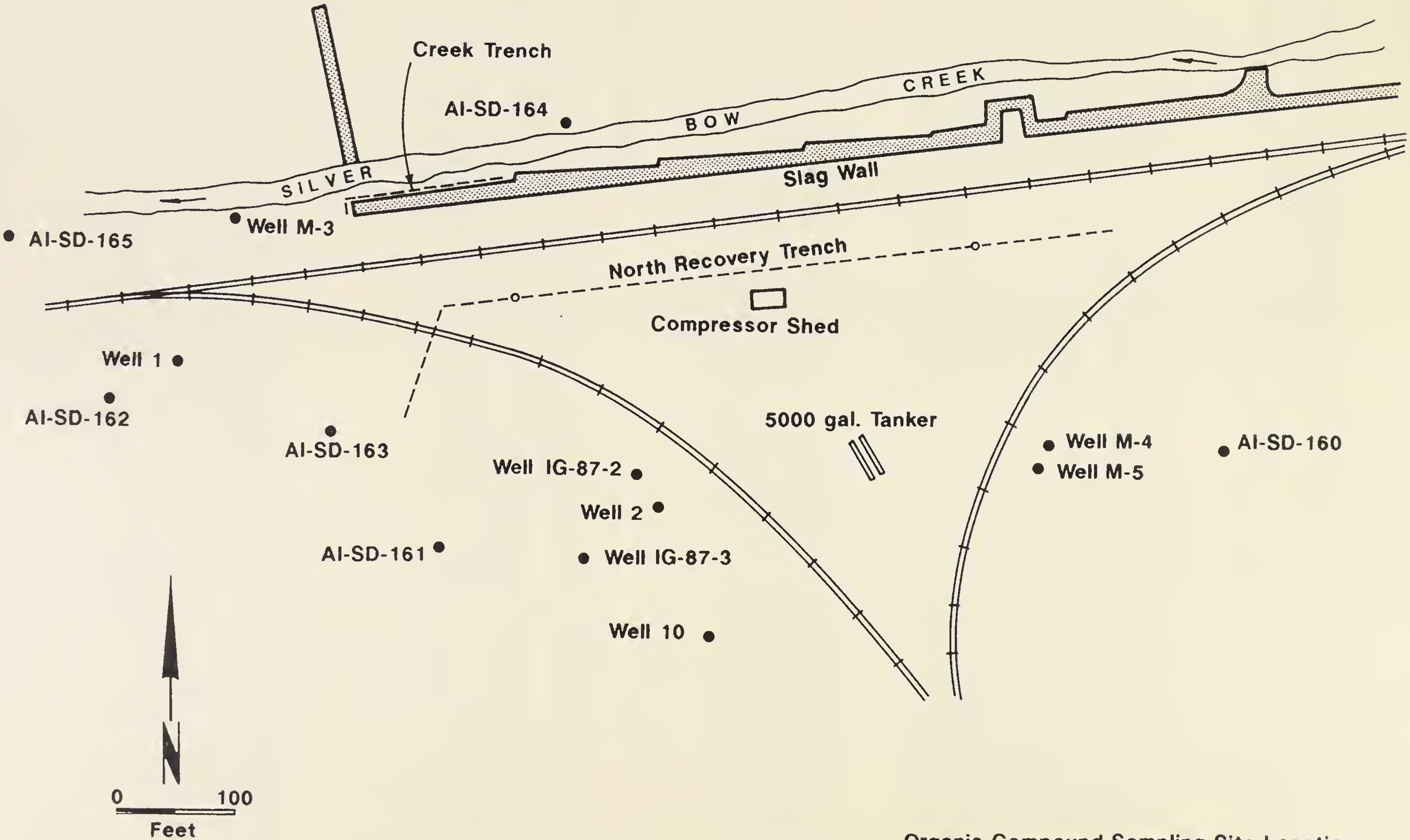
Appendix C-8 presents water soluble data for samples collected during the Area I Phase II Remedial Investigation. Table 4-12 summarizes results of water soluble analyses performed on samples collected in the manganese stockpile area. Examination of these data indicate that metals in samples collected from tailings units 1 and 2 and railroad bed fill (unit 5) are readily soluble in water.

One particular sample exhibited water soluble metals concentrations much greater than other samples collected from the manganese stockpile area. This sample (AI-SD-184-01) was a very fine grained (91.7% less than 200 sieve size) tailings material located under and adjacent to a manganese slagwall along the north end of the manganese stockpile area. The material appeared to be very old mill tailings predating construction of the slag wall. Concentrations of water soluble arsenic and copper were measurably higher in this sample compared to other samples collected for this analysis.

Organic Compounds

Six surface and four subsurface soil samples were collected from an area north of the Montana Pole and Treating Company CERCLA site for analysis of CLP RAS organic compounds. Locations of sampling sites and their relation to existing recovery wells, trenches, railways and Silver Bow Creek are shown on Figure 4-43. Sample sites are numbered A1-SD-160 through A1-SD-165.

The purpose of sampling organic compounds in soils in this portion of Area I was to determine if measurable off-site migration of organic contaminants from the Montana Pole



Map Source: Ecology and the Environment, 1988

Organic Compound Sampling Site Locations
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-43

site is occurring and also to determine if other organic compound source areas were present within Area I, in the vicinity of the Montana Pole site. Analytical results for organic sampling completed during the Phase II Remedial Investigation are contained in Appendix C-13.

Observations made during sampling activities indicated that visible petroleum product was present at sampling site 161 at a depth of 50 to 54 inches below ground surface. Sampling site 161 is located upgradient of the north recovery trench and downgradient of monitoring wells #2, #10, 1G-87-2 and 1G-87-3 (Figure 4-43). This sample contained detectable concentrations xylenes (230 to 1900 mg/kg), a common component of petroleum hydrocarbons. Other detectable compounds in the samples obtained from sampling site 161 included, pentachlorophenol (42,000 to 97,000 μg/kg) and phenanthrene (14,000 to 32,000 μg/kg).

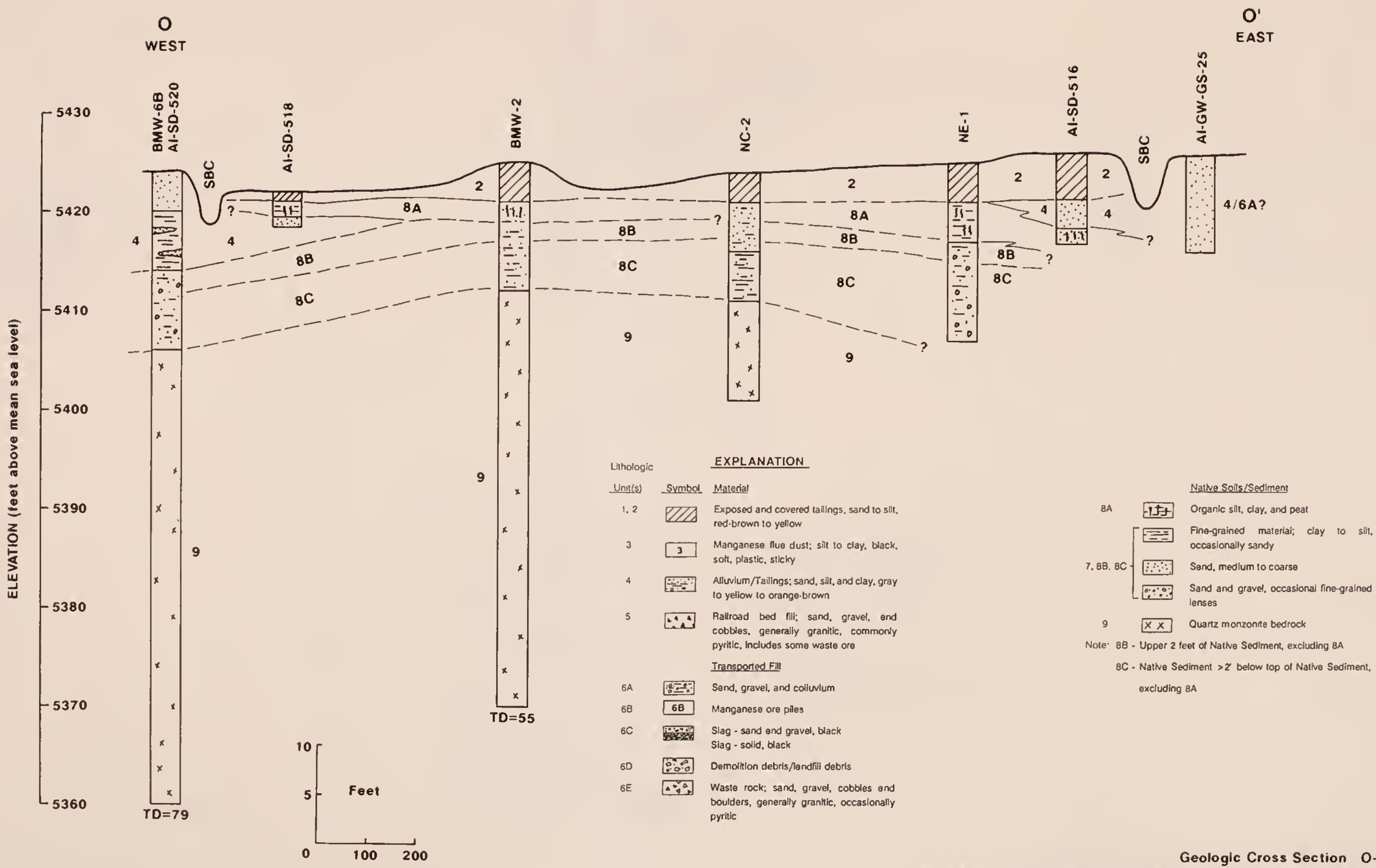
Sample sites 162, 163, 164, and 165 (Figure 4-43) were selected in an attempt to bracket the extent of any downgradient migration of product observed at site 161. Field observations and analytical data for downgradient sample sites (Appendix C-13) indicated no detectable occurrence of any organic compounds analyzed.

4.3.5 Colorado Tailings Area

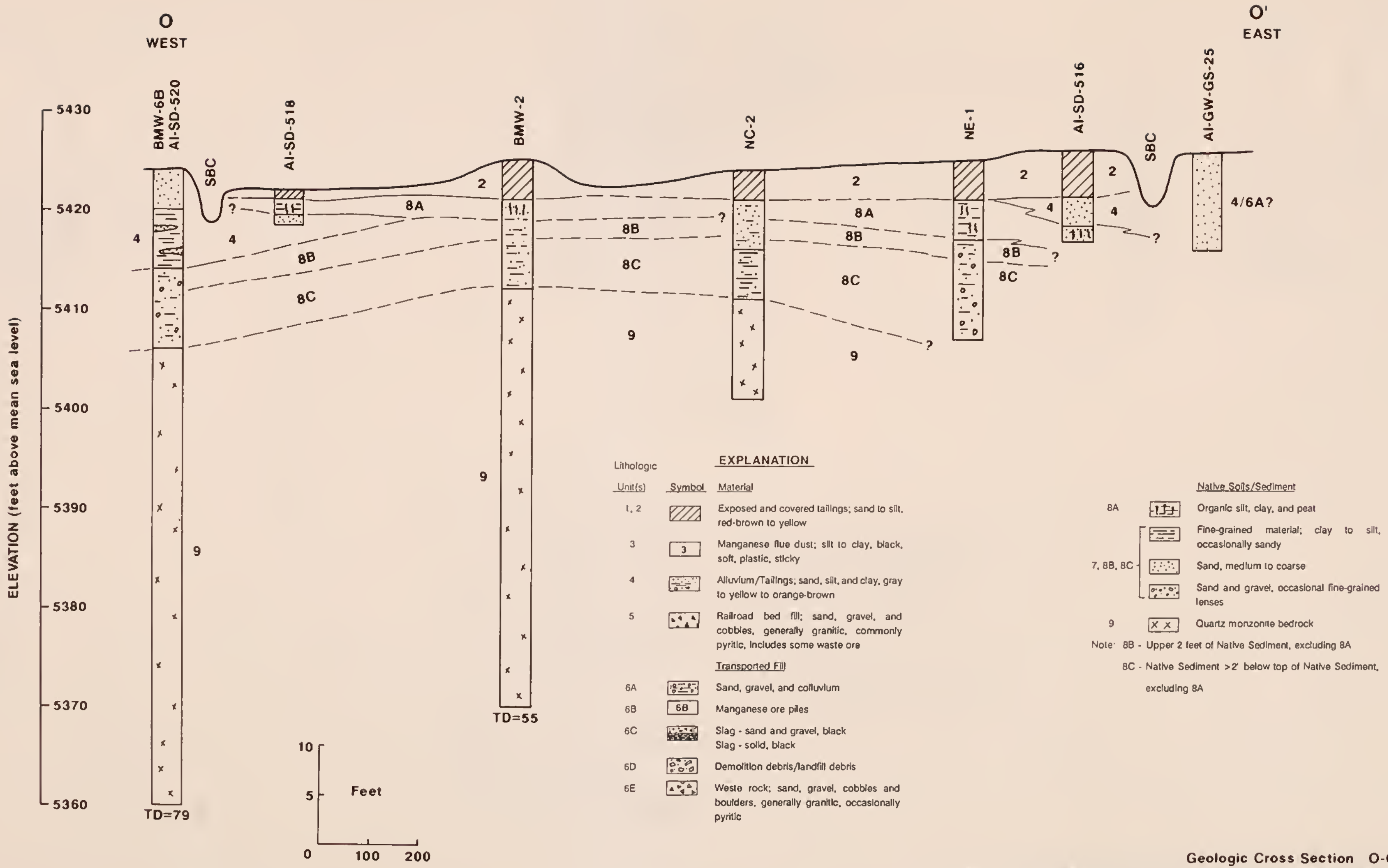
The Colorado Tailings consists of an area of approximately 40 acres located west of the Butte Sewage Treatment Plant (Figure 4-2). The area has historically been used for tailings and mine and mill waste disposal, primarily in association with the Colorado Smelter. The Colorado Tailings area is bounded to the south by Interstate 90/15 and to the north by Silver Bow Creek (Exhibit II).

4.3.5.1 Subsurface Lithology

Lithologies in the area generally include exposed tailings, covered tailings, alluvium/tailings, transported fill, and organic silts and clay overlying native sediments. Subsurface material units encountered at the site are plotted on a series of cross sections. Locations of these cross sections are shown on Figure 4-31. Figure 4-44 is east-west geologic cross section O-O' through the northern part of the Colorado Tailings area. Figure 4-45 is east-west



Geologic Cross Section O-O'
East-West through the Northern Part of the Colorado Tailings Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-44



Geologic Cross Section O-O'
East-West through the Northern Part of the Colorado Tailings Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-44

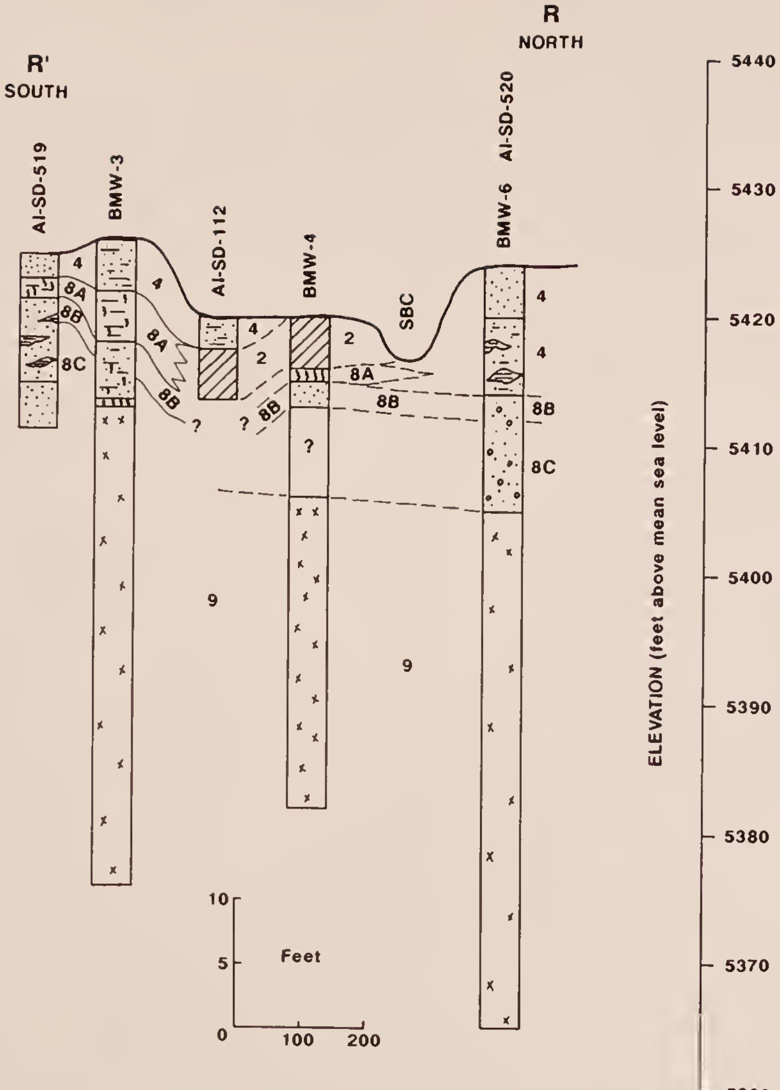
geologic cross section P-P' through the southern portion of the Colorado Tailings area. Figure 4-46 displays north-south oriented geologic cross sections Q-Q' and R-R' through the central and western portions of the Colorado Tailings area, respectively.

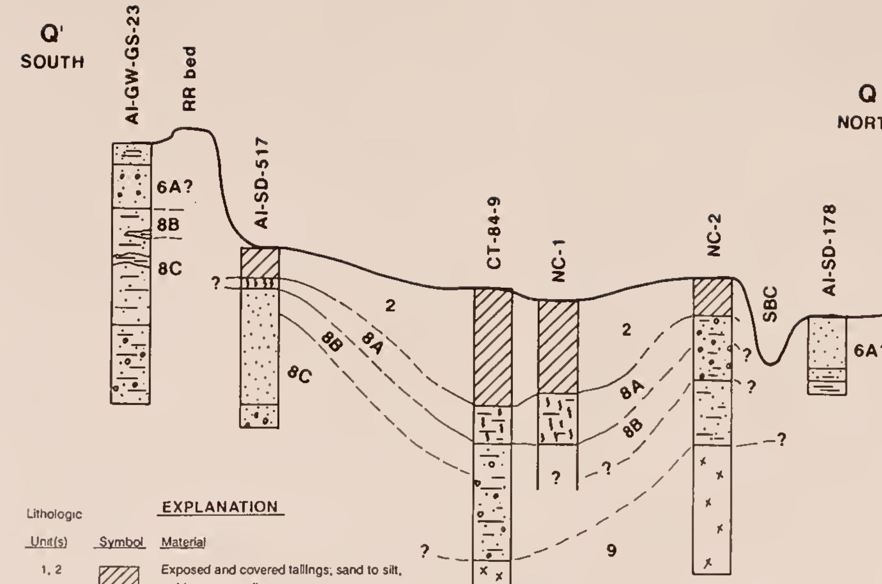
Geologic cross sections generally indicate that the Colorado Tailings area has been covered with a fairly uniform thickness of tailings material. Geologic cross section O-O' (Figure 4-44) indicates that the tailings material (material unit 2) is relatively continuous and generally overlies an organic silt and clay layer (material unit 8A). Geologic cross section P-P' through the southern portion of the area indicates that lithologies in this area are typified by alluvium-tailings (material unit 4) and slag sand and gravel fill (material unit 6C) overlying native sediment (material unit 8B).

Isopach maps prepared for combined material units 2 and 4 and for all overburden overlying material unit 8B in the Colorado Tailings area are presented in Figures 4-35 and 4-36, respectively. Figure 4-35 indicates that thicknesses of tailings (unit 2) and alluvium-tailings (unit 4) are relatively consistent and range from 0 to 4.5 feet in the area. The maximum combined thickness of 4.5 feet for these two material units was encountered in boring A1-SD-516 (Figure 4-35).

Figure 4-36 shows the approximate thickness of all material units overlying native sediment (material unit 8B). This isopach map indicates that central and southeastern portions of the Colorado Tailings area appear to contain the thickest deposits of material overlying native sediment. These materials typically consist of transported fill (units 6A and 6C) , tailings (unit 2), and alluvium/tailings (unit 4) and appear to thin to the north and south. Total thickness of fill in the Colorado Tailings area ranges from 0 to 18 feet thick.

Grain size analyses were performed on three samples collected from the Colorado Tailings area; these data are contained in Appendix C-4. Two grain size analyses were completed on covered tailings material (samples 516-10 and 517-09) and one analysis was performed on organic silt and clay (sample 518-04) (Appendix C-4). Analyses of covered tailings samples (unit 2) indicated that the material contains 20% to 24% fines (-200 mesh) and are classified as a silty sand (SM) using the Unified Soil Classification system. The sample of organic silt and clay (unit 8A) contained 56% fines and was classified as an organic silt (OL) or organic clay (OH).





EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore
		Transported Fill
6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic
		Native Soils/Sediment
8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9		Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Sections Q-Q' and R-R'
North-South through the Colorado Tailings Area
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-46

Volume estimates for combined material units 2 and 4 and of all material units overlying material unit 8B in the manganese stockpile area are contained in Table 4-9. The estimated volume of material units 2 and 4 (tailings and mixed alluvium-tailings) is 230,000 cubic yards. The estimated volume of material overlying material unit 8D (native material) is 582,000 cubic yards.

4.3.5.2 Subsurface Chemistry

Total Metals

XRF analyses were performed on 70 subsurface material samples from the Colorado Tailings area. Total metals analyses were performed on 38 material samples and water soluble metals analyses performed on three material samples from the area. Appendix C-5 contains XRF predicted concentration data for material samples. Appendix C-6 contains CLP laboratory determined total metals concentrations.

Table 4-15 is a statistical summary of XRF predicted and laboratory determined concentrations of arsenic, cadmium, chromium, copper, lead, and zinc by subsurface material units in the Colorado Tailings area. Average laboratory concentrations of arsenic in material units 2, 4, and 8A are relatively consistent with averages ranging from 366 mg/kg to 787 mg/kg. Concentrations in native sediment deeper than 2 feet (material unit 8C), are 88 mg/kg (Table 4-15). Arsenic concentrations in material unit 6A are also relatively low with an average concentration of 103 mg/kg.

The areal distribution of laboratory determined concentrations and XRF predicted concentrations for arsenic in material units 2 and 4, 6A, 6C, and 8A, and 8B in the Colorado Tailings area are presented in Figures 4-37, 4-38. and 4-39, respectively. Arsenic concentrations do not appear to be higher in any specific portion of the Colorado Tailings area.

Average laboratory determined lead concentrations in the Colorado Tailings area (Table 4-15) range from a high of 1,477 mg/kg in material unit 6A to a low of 19 mg/kg in material unit 8C (native material). The organic silt and clay zone within the area (unit 8A) exhibited an average lead concentration of 266 mg/kg. Material units 4 (alluvium-tailings)

[illegible]E 4-15

STATICTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
OR SUBSURFACE MATERIAL UNITS, COLORADO TAILINGS AREA
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
2	Covered tailings												
	Geometric Mean	613	873	17	7	< 18	2	< 1540	1446	< 661	657	1366	2849
	Arithmetic Mean	713	1089	18	11	< 20	2	< 3661	5989	< 897	1152	2287	4052
	Standard Deviation	494	944	8	9	10	2	5859	7790	629	1440	2822	3283
	Maximum	2034	2500	34	23	49	5	21720	16700	2759	3280	9385	7680
	Minimum	360	553	8	2	< 7	1	< 473	123	< 554	268	290	808
	Total No. of Samples	11	4	11	4	11	4	11	4	11	4	11	4
	No. Above Detection	11	4	11	4	9	4	10	4	9	4	11	4
4	Alluvium / Tailings												
	Geometric Mean	< 424	856	26	13	< 22	< 2	2593	3228	< 809	1229	5036	6572
	Arithmetic Mean	< 826	1175	34	22	< 26	< 5	7454	5544	< 1430	2501	10342	10685
	Standard Deviation	688	1167	25	23	16	1	12638	6075	1223	2950	12299	9169
	Maximum	2787	2900	96	55	79	12	42980	14400	4352	6640	42780	22000
	Minimum	< 363	451	7	2	< 4	< 9	362	586	< 424	258	763	1030
	Total No. of Samples	13	4	13	4	13	4	13	4	13	4	13	4
	No. Above Detection	8	4	13	4	12	2	13	4	10	4	13	4
8A	Native soils: Organic silts, clays, and peat												
	Geometric Mean	< 435	366	25	< 9	< 20	< 8	5884	3441	< 796	266	< 4434	3930
	Arithmetic Mean	< 774	841	48	< 39	< 25	< 12	13637	9389	< 1341	799	<16373	10505
	Standard Deviation	671	1074	48	47	14	6	17324	11853	973	1163	20186	13327
	Maximum	3019	2910	127	113	57	24	49610	25600	3504	2990	62950	31800
	Minimum	< 410	35	2	< 4	< 4	< 6	527	355	< 289	40	< 500	257
	Total No. of Samples	8	6	8	6	8	6	8	6	8	6	8	6
	No. Above Detection	5	6	8	5	7	5	8	6	6	6	7	6
8B	Native soils: Sand, gravel, silt; upper 2 ft												
	Geometric Mean	< 133	81	7	< 1	< 21	7	916	680	< 203	124	753	668
	Arithmetic Mean	< 182	134	9	< 2	< 22	9	1045	1102	< 207	253	1205	1463
	Standard Deviation	39	161	7	0	4	5	616	948	38	345	1226	2050
	Maximum	520	320	21	5	27	12	2177	2030	0	652	3079	3830
	Minimum	< 520	32	2	< 5	< 14	3	423	136	< 0	50	213	253
	Total No. of Samples	6	3	6	3	6	3	6	3	6	3	6	3
	No. Above Detection	1	3	6	1	5	3	6	3	0	3	6	3
8C	Native soils: Sand, gravel, silt; below 2 ft												
	Geometric Mean	< 53	88	5	< 1	< 22	5	< 536	297	< 210	19	< 431	158
	Arithmetic Mean	< 98	713	6	< 1	< 22	5	< 664	534	< 228	21	< 509	188
	Standard Deviation	34	1000	3	0	1	3	333	628	46	15	208	144
	Maximum	460	1420	9	1	20	8	1462	978	356	32	896	290
	Minimum	< 460	6	2	< 1	< 14	3	< 249	90	< 286	11	< 245	86
	Total No. of Samples	8	2	8	2	8	2	8	2	8	2	8	2
	No. Above Detection	1	2	8	1	2	2	7	2	3	2	7	2

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

and 2 (covered tailings) contain average lead concentrations of 821 mg/kg and 620 mg/kg, respectively.

Figures 4-40, 4-41, and 4-42 contain laboratory determined concentrations of lead in material units 2 and 4; 6A, 6C, and 8A; and 8B respectively for the Colorado Tailings Area. Lead concentrations in all material units appear to be quite variable throughout the site. Only limited data are available for material unit 8B in the colorado Tailings area (Figure 4-42).

Statistical summaries of XRF predicted concentrations and laboratory concentrations of cadmium, chromium, copper, and zinc for the Colorado Tailings area are also contained in Table 4-15. Average laboratory concentrations of cadmium were highest in material unit 8A (39 mg/kg) and lowest in material unit 8C (1 mg/kg). Average laboratory-determined concentrations of chromium are highest in material unit 8A (organic peat) at 12 mg/kg and lowest in material unit 2 (tailings) at 4 mg/kg.

Average laboratory concentrations of copper range from a high of 9,388 mg/kg in native organic silt (8A) and a low of 423 mg/kg in native sand greater than 2 feet deep (8C). Average laboratory concentrations of zinc range from a high of 10,500 mg/kg in material unit 8A and a low of 179 mg/kg in material unit 8C. In general, average laboratory concentrations of copper and zinc were highest in material units 2, 4, 6A, 6C, and 8A and lowest in material units 8B and 8C.

<u>Metals by Grain Size</u>

Three subsurface material samples obtained from the Colorado Tailings area were analyzed for total metals by grain size. Material units analyzed include covered tailings (unit 2) and organic silt and clay (unit 8A). Total metals by grain size data are contained in Appendix C-7. Table 4-11 summarizes resultant laboratory concentrations for selected metals of the -80 to +200 mesh material, -200 mesh material, rinseate water used to wash the sample through the sieves, and total metals concentrations for sample splits using the entire sample.

Concentrations of arsenic, cadmium, chromium, copper, lead, and zinc in the -200 sieve fraction are generally 1.5 to 10 times higher than concentrations in the -80 to +200 size

fraction in the covered tailings samples. Concentrations of metals in the entire sample are typically slightly higher than concentrations in the -80 to +200 mesh size fraction. Metals concentration in rinseate water varies considerably from sample to sample, but generally comprise only one to five percent of the total weight percent of metals present in the sampled materials.

Water Soluble Metals

Three samples from the Colorado Tailings area were analyzed for soluble metals (Table 4-12). Two of these samples were obtained from covered tailings (unit 4). These samples exhibited relatively high water soluble concentrations of copper and zinc and somewhat lower concentrations of arsenic and cadmium. Water soluble metals concentrations in organic silt and clay unit 8A (sample 518-04, Table 4-12) were relatively low except for cadmium and zinc which were 330 and 22,000 μg/L, respectively.

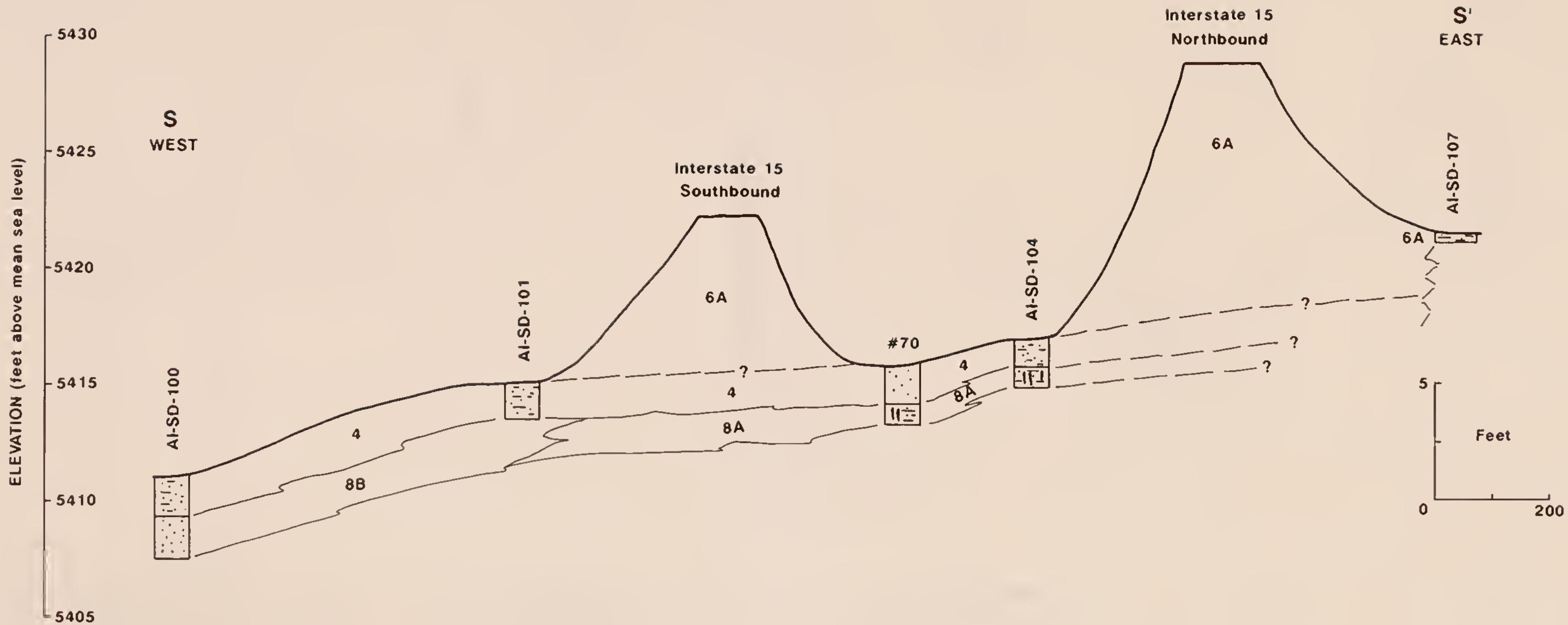
4.3.6 Area West of the Colorado Tailings

The area west of the Colorado Tailings and within Area I extends from the Colorado Tailings down Silver Bow Creek about one-half mile. The area is bounded on the south by a railway roadbed and on the north by a county road (Figure 4-2).

4.3.6.1 Subsurface Lithology

The eastern half of the area west of the Colorado Tailings has been extensively altered by interstate highway construction. Because of this, Silver Bow Creek has been channelized for about 1200 feet where the stream flows under Interstate 90/15. West of Interstate 90/15, Silver Bow Creek retains a more natural character although there is extensive evidence of fluvially deposited tailings adjacent to the stream and within associated high-flow meander channels.

Surficial and near surface material units encountered in this portion of Area I include units 4 (mixed alluvium-tailings) with units 8A or 8B at depth and unit 6A (transported fill). Subsurface material units are shown on cross-sections S-S', T-T' and U-U' (Figures 4-47 and 4-48). Locations of these Cross sections are shown on Figure 4-31. East west section S-S'



EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore

Transported Fill

6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic

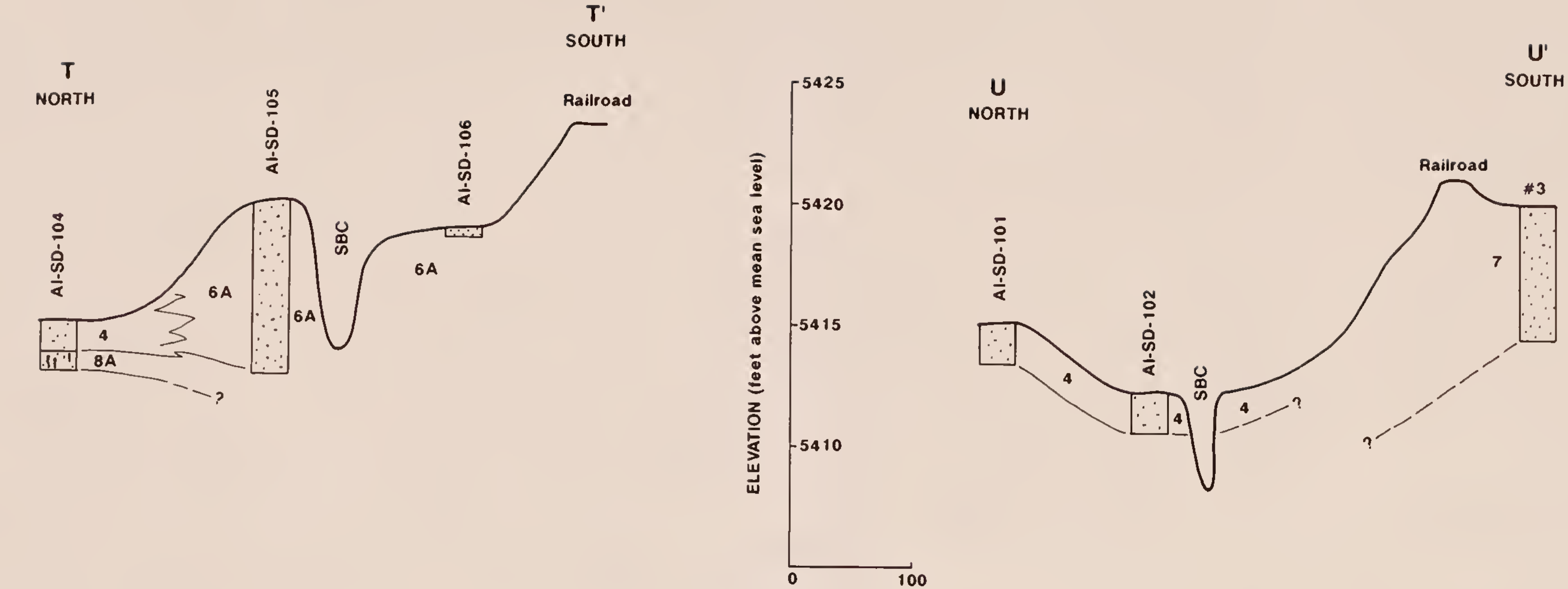
Native Soils/Sediment

8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9		Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Section S-S'
East-West through the Area West of the Colorado Tailings
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-47



EXPLANATION

Lithologic Unit(s)	Symbol	Material
1, 2		Exposed and covered tailings; sand to silt, red-brown to yellow
3	3	Manganese flue dust; silt to clay, black, soft, plastic, sticky
4		Alluvium/Tailings; sand, silt, and clay, gray to yellow to orange-brown
5		Railroad bed fill; sand, gravel, and cobbles, generally granitic, commonly pyritic, includes some waste ore

Transported Fill

6A		Sand, gravel, and colluvium
6B	6B	Manganese ore piles
6C		Slag - sand and gravel, black Slag - solid, black
6D		Demolition debris/landfill debris
6E		Waste rock; sand, gravel, cobbles and boulders, generally granitic, occasionally pyritic

Native Soils/Sediment

8A		Organic silt, clay, and peat
7, 8B, 8C		Fine-grained material; clay to silt, occasionally sandy
		Sand, medium to coarse
		Sand and gravel, occasional fine-grained lenses
9	X X	Quartz monzonite bedrock

Note: 8B - Upper 2 feet of Native Sediment, excluding 8A

8C - Native Sediment >2' below top of Native Sediment, excluding 8A

Geologic Cross Sections T-T' and U-U'
North-South through the Area West of Colorado Tailings
Area I Operable Unit Phase II Remedial Investigation
FIGURE 4-48

shows the thickness of unit 4 (mixed alluvium-tailings) is relatively consistent at about 1.5 feet along the north side of Silver Bow Creek. Mixed native materials 8A or 8B generally underlie unit 4 in this cross section (Table 4-5).

Transverse cross-sections T-T' and U-U' (Figure 4-48) show the effects of channelization on the stream and the impacts this had on distribution of alluvial materials. Unit 4 material from the interstate fill west to the end of the dike on the north side of Silver Bow Creek may have been trapped behind the dike. Materials west of there are subject to transport by the meandering stream.

Grain size, water soluble metals, and total metals by grain size analyses were not completed on any samples collected from the area west of the Colorado Tailings.

4.3.6.2 Subsurface Chemistry

XRF analyses were performed on 29 material samples collected from the area west of the Colorado Tailings; total metals analyses were performed on 22 of these samples. XRF data are contained in Appendix C-5 and total metals data are contained in Appendix C-6. Table 4-16 summarizes XRF and laboratory concentrations of arsenic, cadmium, chromium, copper, lead, and zinc for subsurface materials in the area west of the Colorado Tailings.

Arsenic concentrations in material units 2 and 4 in the area west of the Colorado Tailings are shown on Figure 4-37. The three sample sites located farthest from the creek (samples AI-SD-100, 101 and 104) show highest concentrations, ranging from 386 mg/kg to 482 mg/kg, while site AI-SD-520 contained the lowest arsenic concentration.

Figure 4-38 shows XRF predicted and total arsenic concentrations for units 6A, 6C, and 8A for the area west of the Colorado Tailings. Laboratory determined arsenic concentrations in these units were relatively low, ranging from 46 mg/kg to 104 mg/kg.

Figure 4-39 shows XRF predicted and total arsenic concentrations for unit 8B west of the Colorado Tailings. Arsenic concentrations in unit 8B were only determined at one sampling location (AI-SD-100) and were relatively low (68 mg/kg).

TABLE 4-16
STATISTICAL SUMMARY OF XRF AND LABORATORY CONCENTRATIONS
OF ARSENIC, CADMIUM, CHROMIUM, COPPER, LEAD, AND ZINC
OR SUBSURFACE MATERIAL UNITS, AREA WEST OF THE COLORADO TAILINGS
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

03/03/90

Chemical Concentrations (1)

Map Unit No.	Material Description / Statistical Parameter	Arsenic XRF	Arsenic Lab	Cadmium XRF	Cadmium Lab	Chromium XRF	Chromium Lab	Copper XRF	Copper Lab	Lead XRF	Lead Lab	Zinc XRF	Zinc Lab
4	Alluvium / Tailings												
	Geometric Mean	< 156	91	< 7	< 2	< 39	< 3	< 971	408	< 566	341	< 1393	1535
	Arithmetic Mean	< 356	269	< 17	< 3	< 49	< 7	< 2238	1626	< 2230	3246	< 5893	3942
	Standard Deviation	86	291	16	1	28	5	2939	1984	204	3727	5549	3723
	Maximum	1000	529	41	7	106	15	8845	4270	6694	6700	16930	8120
	Minimum	< 804	12	< 2	< 5	< 25	< 2	< 508	17	< 5982	9	< 827	70
	Total No. of Samples	6	4	6	4	6	4	6	4	6	4	6	4
	No. Above Detection	2	4	5	2	4	3	5	4	2	4	4	4
6A	Transported fill: Natural Alluvium												
	Geometric Mean	< 31	(4)	3	(4)	< 24	(4)	470	(4)	< 129	(4)	381	(4)
	Arithmetic Mean	< 32	(4)	3	(4)	< 24	(4)	470	(4)	< 129	(4)	381	(4)
	Standard Deviation	0	(4)	0	(4)	0	(4)	0	(4)	0	(4)	0	(4)
	Maximum	0	(4)	3	(4)	0	(4)	470	(4)	0	(4)	381	(4)
	Minimum	< 0	(4)	3	(4)	< 0	(4)	470	(4)	< 0	(4)	381	(4)
	Total No. of Samples	1		1		1		1		1		1	
	No. Above Detection	0		1		0		1		0		1	
8A	Native soils: Organic silts, clays, and peat												
	Geometric Mean	< 135	104	20	8	40	21	904	575	1153	1340	4739	3690
	Arithmetic Mean	< 135	104	20	8	40	21	904	575	1153	1340	4739	3690
	Standard Deviation	0	0	0	0	0	0	0	0	0	0	0	0
	Maximum	0	104	20	8	40	21	904	575	1153	1340	4739	3690
	Minimum	< 0	104	20	8	40	21	904	575	1153	1340	4739	3690
	Total No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1
	No. Above Detection	0	1	1	1	1	1	1	1	1	1	1	1
8B	Native soils: Sand, gravel, silt; upper 2 ft												
	Geometric Mean	< 83	67	8	7	< 33	3	894	851	< 555	1231	1096	2061
	Arithmetic Mean	< 101	69	11	7	< 34	4	942	934	< 849	1276	1486	2065
	Standard Deviation	60	20	8	1	6	4	359	546	351	473	1034	191
	Maximum	0	83	17	7	45	7	1300	1320	1581	1610	2242	2200
	Minimum	< 0	54	2	6	< 33	1	582	548	< 836	941	308	1930
	Total No. of Samples	3	2	3	2	3	2	3	2	3	2	3	2
	No. Above Detection	0	2	3	2	2	2	3	2	2	2	3	2
8C	Native soils: Sand, gravel, silt; below 2 ft												
	Geometric Mean	< 31	15	5	< 0	< 24	13	366	202	< 129	33	< 120	162
	Arithmetic Mean	< 32	15	5	< 0	< 24	13	366	202	< 129	33	< 120	162
	Standard Deviation	0	0	0	0	0	0	0	0	0	0	0	0
	Maximum	0	15	5	0	0	13	366	202	0	33	0	162
	Minimum	< 0	15	5	< 0	< 0	13	366	202	< 0	33	< 0	162
	Total No. of Samples	1	1	1	1	1	1	1	1	1	1	1	1
	No. Above Detection	0	1	1	0	0	1	1	1	0	1	0	1

NOTES:
1) Concentration units are mg/Kg.
2) Statistics are computed from data for natural samples.
3) For statistical purposes values below detection are treated as being at 1/2 the detection limit.
4) No usable records were found for this site.

Figure 4-40 shows XRF predicted concentrations and laboratory concentrations for lead in units 2 and 4 for the area west of Colorado Tailings. Three samples obtained from abandoned, unvegetated, or poorly vegetated meander channels (samples AI-SD-100, 101, and 104) contained relatively high concentrations of lead. Individual analyses of a sandy soil horizon between 10 and 20 inches below ground surface at these sites showed lead levels ranged between 5600 and 6700 mg/kg (Appendix C-3). Laboratory concentrations of lead in tailings (unit 2) and alluvium-tailings material (unit 4) encountered in borings AI-SD-102, 108, and 520 were relatively low, ranging from 23 mg/kg to 598 mg/kg.

Figure 4-41 shows XRF predicted and total lead concentrations for units 6A and 8A west of the Colorado Tailings. Laboratory concentrations of lead in these material units are highest in boring AI-SD-104 at 1340 mg/kg and lowest in boring AI-SD-107 at 49 mg/kg. Laboratory determined concentrations of lead in two samples of material unit 8B in boring AI-SD-100 average 1276 mg/kg.

4.3.7 EP Toxicity Data

Samples selected for EP Toxicity analysis included those which exhibited relatively high XRF predicted concentrations for arsenic, cadmium, and lead. Of the 15 samples selected, three exceeded maximum EP Toxicity concentrations for either cadmium or lead. Samples which exceeded established standards for this test included AI-SD-506-11 (lead) and AI-SD-509-09 (cadmium) from the manganese stockpile area and AI-SD-518-04 (cadmium) from the Colorado Tailings area. The former two samples were categorized into material unit 4 (mixed alluvium and tailings); the latter sample was obtained from material unit 8A which is an organic peat layer typically between overlying tailing material and underlying native sediments.

EP Toxicity data are contained in Appendix C-9. Table 4-17 summarizes EP Toxicity data for both surface and subsurface samples collected during the Phase II Remedial Investigation.

TABLE 4-17

SUMMARY OF EP TOXICITY LABORATORY DATA FOR SURFACE AND SUBSURFACE MATERIALS; AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Area	Sample No.	Material Unit	Depth (feet)	CONCENTRATION (μg/L) As	Ba	Cd	Cr	Pb	Hg	Se	Ag
Upper Metro Storm Drain Area	611-18	2	22.0-25.3	11	117	<2	<6	<25	<0.15	<1	<7
Upper Metro Storm Drain Area	606-09	6C	2.0-5.5	5	154	44	<6	<25	<0.15	<1	<7
Upper Metro Storm Drain Area	614-10	8C	12.0-20.0	0.6	207	3	<6	<25	<0.15	<1	<7
Lower Metro Storm Drain Area	123-01	4	0.0-1.2	9.6	80.5	110	<5.5	33.2	<0.15	<1.1	<7
Lower Metro Storm Drain Area	179-01	6D	0.0-5.6	161	207	10.8	<5.5	71.3	<0.15	<1.1	<7
Manganese Stockpile Area	505-01	1	0.0-0.1	3	96	300	6	<25	0.4	<1	<7
Manganese Stockpile Area	152-01	2	0.0-1.3	25.0	104	85.7	<5.5	84.6	<0.15	<1.1	<7
Manganese Stockpile Area	507-11	2	2.0-3.5	10	115	23	<6	42	0.4	<1	<7
Manganese Stockpile Area	506-11	4	6.0-9.5	27	31	339	<6	17900*	0.4	<1	<7
Manganese Stockpile Area	509-09	4	0.8-2.8	9	72	1620*	<6	51	<0.15	<1	<7
Manganese Stockpile Area	186-01	5	0.0-0.3	6.6	75.2	917	<5.5	447	<0.15	<1.1	<7
Colorado Tailings Area	515-10	4/8A	12.0-15.5	10	199	277	8	2660	<0.15	<1	<7
Colorado Tailings Area	518-04	8A	1.5-2.5	2	111	1030*	6	<25	0.25	<1	<7
Area West of Colorado Tailings	100-03	4	0.8-1.7	293	112	43.8	<5.5	1310	<0.15	<1.1	<7
Area West of Colorado Tailings	104-02	4	0.1-1.2	31.4	212	131	<5.5	3310	0.86	<1.1	<7

* Exceeds EP Toxicity Maximum Concentrations

4.3.8 X-ray Diffraction Data

X-ray diffraction (XRD) analyses were performed on a variety of material units, including: exposed and covered tailings (units 1 and 2); manganese flue dust (unit 3);, alluvium/tailings (unit 4); railroad bed fill (unit 5); transported fill (units 6A and 6C); organic silts (unit 8A); and, native material (unit 8C). Appendix C-10 contains laboratory data sheets for XRD analyses. Tables 4-18 and 4-19 summarize X-ray diffraction data for surface and subsurface samples, respectively.

Data for surface material samples indicate that exposed tailings (unit 1), alluvium/tailings (unit 4), transported fill sediment with slag (units 6A/C), and railroad bed material (unit 5) are composed primarily of quartz, plagioclase feldspar, potassium feldspar, and mica/illite (Table 4-18). Several surface samples (e.g. AI-SD-151-01, 184-01, and 185-01) contained 20 to 25 percent jarosite. Jarosite is an anhydrous potassium and iron sulfate containing hydroxyl; its chemical formula is $KFe_3(SO_4)_2(OH)_6$. Jarosite is a typical secondary mineral of ferruginous ores and occurs in limonitic gossans.

Surface samples AI-SD-100-01, 111-01 and 505-01 contained from seven to 18 percent gypsum which is a hydrated calcium sulfate (Table 4-18). One of the four exposed railroad bed fill material samples contained 9 percent pyrite.

X-ray diffraction data for subsurface material samples indicate that the predominant minerals in subsurface materials in Area I are potassium feldspar, plagioclase feldspar, quartz, and mice/illite (Table 4-19). These minerals comprise 75 to 90 percent of the sediment. One sample of slag rich sand from the upper Metro Storm Drain (AI-SD-606-09) contained 20 % quartz and 80 % alpha-iron. All other material samples, including those from the deep monitoring well AI-GW-GS-50 appear to be composed of minerals typically found in granite.

4.3.9 Bulk Density

Bulk density was determined for eight samples of covered tailings material (material unit 2) collected in the three major impounded tailings areas utilizing shelby sampling tubes. Shelby sampling tubes are thin walled steel sampling cylinders. The tubes were pushed into

LE 4-18

SUMMARY OF X-RAY DIFFRACTION LABORATORY DATA FOR SURFACE MATERIAL AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Area	Sample No.	Lithologic Unit	Depth (feet)	MINERAL CONCENTRATION (%)													
				Potassium Feldspar	Plagioclase Feldspar	Quartz	Mica/Illite	Jarosite	Gypsum	Pyrite	Sphalerite	Amphibole	Magnetite	Chlorite	Kaolinite	Clay(s)	Alum-group
Area West of Colorado Tailings	100-01	4	0.0-0.1	15	18	25	7		18	5		7					
Colorado Tailings	111-01	6A/C	0.0-0.1	20	20	30	<10		7				<5				
Manganese Stockpile	505-01	1	0.0-0.1	21	27	27			11	<5		<10			<5		
Manganese Stockpile	116-01	1	0.0-0.1	<5		45	40		<5	5						<5	
Manganese Stockpile	184-01	1	0.0-0.1	5	<5	45	20	25									<5
Manganese Stockpile	151-01	5	0.0-0.2	12	<5	25	22	25							7		
Manganese Stockpile	185-01	5	0.0-0.1	10		30	15	20	<5	<5				10		<10	
Manganese Stockpile	186-01	5	0.0-0.3	10	<5	45	20		<5	9	<5				<5		
Lower Metro Storm Drain	176-01	5	0.0-0.1		<5	53	30	7									

Percents do not always add up to 100 since amorphous material is not distinguished on the XRD pattern.

LE 4-19

SUMMARY OF X-RAY DIFFRACTION LABORATORY DATA FOR SUBSURFACE MATERIAL
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Area	Sample No.	Lithologic Unit	Depth (feet)	MINERAL CONCENTRATION (%) Potassium Feldspar	Plagioclase Feldspar	Quartz	Mica/Illite	Jarosite	Gypsum	Pyrite	Sphalerite	Amphibole	Calcite	Siderite	Smithsonite	Magnetite	Chlorite	Clay(s)	Alpha-Iron	Dolomite	Cryptomelane	Bixbyite
Upper Metro Storm Drain	611-18	2	22.0-26.5	<5		80	10	<5														
Upper Metro Storm Drain	606-09	6C	2.0-5.5			20													80			
Upper Metro Storm Drain	614-10	8C	12.0-20.0	26	21	31	11							<5		<5				<5		
Upper Metro Storm Drain	GW-GS-50	8C	162-164	25	20	30	10											10				
Upper Metro Storm Drain	GW-GS-50	8C	166-167	35	30	25	<10															
Upper Metro Storm Drain	GW-GS-50	8C	168-170	15	15	20	25											<10				
Upper Metro Storm Drain	GW-GS-50	8C	242-244	24	31	25	<10					<10				<5						
Upper Metro Storm Drain	GW-GS-50	8C	245	15	25	25	20							<5		5				<5		
Upper Metro Storm Drain	GW-GS-50	8C	244-248	16	16	25	16										12					
Upper Metro Storm Drain	GW-GS-50	8C	270	20	40	15	12					8		<5								

TABL[illegible]–continued

SUMMARY OF X-RAY DIFFRACTION LABORATORY DATA FOR SUBSURFACE MATERIAL
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

Area	Sample No.	Lithologic Unit	Depth (feet)	MINERAL CONCENTRATION (%) Potassium Feldspar	Plagioclase Feldspar	Quartz	Mica/Illite	Jarosite	Gypsum	Pyrite	Sphalerite	Amphibole	Calcite	Siderite	Smithsonite	Magnetite	Chlorite	Clay(s)	Alpha-Iron	Dolomite	Cryptomelane	Bixbyite
Lower Metro Storm Drain	129-01	4	0.0-0.8	10	<10	35	15	10				<5										
Manganese Stockpile	507-11	2	2.0-3.5	5		77	10	5														
Manganese Stockpile	150-02	3	0.1-7.9	5		35	<10						<5							5	10	
Manganese Stockpile	506-11	4	6.0-9.5	5	<5	60						5				5						10
Manganese Stockpile	509-09	4	0.8-2.8	5	<5	50	23	<5		5	8											
Colorado Tailings	516-10	2	1.0-3.0			80	15															
Colorado Tailings	518-04	8A	1.5-2.5	20	20	25	<10		12			5			<5		<5	<5				

the subsurface material with a drill rig, allowed to stabilize for several minutes, and then were extracted slowly. Relatively undisturbed samples of material can be obtained in this manner.

Bulk density of the tailings material collected ranged from 1.59 g/cm^3 to 1.95 g/cm^3. Bulk density values in the three samples collected from the upper Metro Storm Drain area (Parrott Tailings) varied the most, ranging from 1.64 g/cm^3 to 1.95 g/cm^3. Two samples collected from the manganese stockpile area were similar at 1.83 g/cm^3 and 1.87 g/cm^3, and three samples from the Colorado Tailings area ranged from 1.59 g/cm^3 to 1.76 g/cm^3. Appendix C-11 contains results of bulk density determinations.

4.3.10 Acid-Base Account

Soil samples collected from six sites along the middle to lower reaches of the Metro Storm Drain and one site below the Colorado Tailings were analyzed for acid-base account (ABA). Sites selected for this type of analysis were typified by exposed tailing material. Samples analyzed for ABA were obtained from the upper six inches of the soil profile at each site.

ABA, neutralization potential, and SMP lime requirement data are contained in Appendix C-12. These data indicate that most of the acid-generating potential of exposed tailing sites sampled could by neutralized with the addition of 50 to 100 tons of $CaCO_3$ per 1000 tons of soil and tailings. Specific conductivity in samples analyzed ranged from 2.0 to 16.3 μmhos/cm; pH values ranged from 2.2 to 7.2 standard units. A relatively larger percentage of the extractable sulfur in the samples was obtained using the hot water extraction method.

SECTION 5.0 DATA VALIDATION

5.0 DATA VALIDATION

5.1 INTRODUCTION

This section describes contract compliance, data validation and reduction, and presents quality assurance statements for data collection activities associated with the Area I Operable Unit Phase II Remedial Investigation. Environmental samples collected during this investigation included surface water, groundwater, and dispersed and impounded tailings and contaminated soils. Field procedures used during the various investigations and guidelines followed in maintaining quality assurance and quality control during the course of the remedial investigation are described in the project sampling and analysis plan (CH2M HILL, 1989d).

The majority of collected samples were analyzed by contract laboratory program (CLP) laboratories using both routine analytical services and special analytical services. Certain soils analyses including acid-base account, grain size and hydrometer tests, X-ray diffraction, EP Toxicity, and hexavalent chrome analyses were performed by private laboratories outside the CLP programs. Laboratory methods utilized, which included internal laboratory quality control procedures, were stipulated in project sampling and analysis plan (CH2M HILL, 1989d).

5.2 CONTRACT COMPLIANCE SCREENING

Contract compliance screening (CCS) represented the first level of data validation and reduction during the project and was performed for inorganic and organic Routine Analytical Services (RAS) analyses only. This screening is stipulated by EPA and its purpose is evaluate whether contract performance requirements were met by the CLP laboratory in analyzing the submitted samples.

The CCS process involves review and evaluation of each RAS data package received from the CLP laboratories by the Sample Management Office (SMO). Specific guidelines are incorporated into an automated computer system; computer software, as well as contract screening forms, are utilized in completing the screening. Required guidelines have been

established by EPA Region VIII. Guidelines for CCS are found in the document Standard Operating Procedure for Contract Compliance Screening (CCS) of Routine Analytical Services Analyses of Inorganics [Organics] Data Under SOW No. 787 (EPA, 1988).

The major evaluatory parameters used to review data review evaluate contract compliance included the following:

- Sample holding times

- Instrument calibration

- Calibration and preparation of blanks

- Instrument interferences

- Laboratory control samples

- Specific sample results including:

    - Laboratory duplicate sample analysis
    - Spiked sample results and graphite furnace atomic absorption QC analyses
    - Field and other QC sample results

Post-review comments and findings were sent to the USEPA in the Regional Response to Results of Contract Compliance Screening, a document stating analytical difficulties and/or complications in contractual compliance. The Deputy Project Officer for EPA Region VIII handles the resolution of conflicts regarding contract compliance directly with the contract laboratory. Through this process, the laboratories are required by the USEPA to resubmit and re-analyze samples which do not meet terms of the initial contract. Any action addressed by the laboratories is presented in a follow-up document called Laboratory Response to Results of Contract Compliance Screening, stating what action was performed in response to the initial CCS comment.

In general, resolution of problems associated with data generated during the Phase II Remedial Investigation was straightforward. Analytical values resulting from resubmittal of certain samples for laboratory analysis were updated in the project database as they were received from USEPA and were then filed in the administrative record.

5.3 DATA VALIDATION, REDUCTION AND QUALITY ASSURANCE STATEMENTS

Data validation was conducted under separate contract from Contract Compliance Screening. It is an independent data evaluation with the purpose of ensuring analytical methods, blanks, calibration and laboratory standards, and interference check standards meet specific performance standards. Data validation investigates analytical requirements that should be fully under the laboratory's control. Guidelines for this process are located in documents: <u>Laboratory Data Validation, Functional Guidelines For Evaluating Inorganic [Organic] Analyses (EPA, 1988)</u>. This validation process is required for all data packages as stipulated by USEPA, Region VIII. Data validation involves a technical (not contractual) review of the data packages including provisions for qualifying data values outside control windows.

Data validation and reduction also consisted of the development of Quality Assurance Statements for RAS and RAS + SAS data packages (RAS analyses with the addition of lower SAS detection limits). Accuracy, precision, representativeness, comparability, and completeness of laboratory data were qualified and presented in QA reports for each case or set of samples. The protocols for calculating these statements are described in the project sampling and analysis plan (CH2M HILL, 1989d).

5.3.1 <u>Accuracy</u>

Accuracy is measured as the ability of the analytical procedure to determine the actual quantity of a particular analyte in a sample or as a measure of the absence of consistent error. In these studies, accuracy was evaluated by determining the average recovery of the analytes in two different types of QC samples: blind field standards (BFS) inserted into the sample train in the field, and laboratory natural matrix spikes performed in the laboratory.

Blind field standards manufactured by the EPA were used during surface water snowmelt runoff sampling. Priority Pollutant/CLP-Soil and Priority Pollutant/CLP-Water standards, purchased from Environmental Resource Associates, were used during soils and groundwater sampling episodes, respectively. The concentrations of elements in the blind field standards were closely matched to the assumed concentrations of the various environmental matrices within the Area I Operable Unit. These samples were inserted at the prescribed frequency into the sample train in the field.

Completion of laboratory natural matrix spikes were also required within each sample designation group (SDG). The frequency at which these spikes were performed was consistent with that presented in the project sampling and analysis plan (CH2M HILL, 1989d) and also in the Special Analytical Services requests completed for specific analyses. Natural matrix spikes typically work well on homogeneous samples, such as water but poor recoveries are possible for soil samples because of the nonhomogeneous nature of the material.

Accuracy statements were prepared for each element in each sample matrix which used blind field standards using the statistical methodology described in the project sampling and analysis plan (CH2M HILL, 1989d).

5.3.2 Precision

Precision is a measure of the mutual agreement characteristic of individual measurements of identical samples. In these studies, two different types of QC samples were used to evaluate precision. These included blind field replicates and laboratory duplicates. Blind field replicates were collected, designated, and inserted into the sample train in the field at a frequency stipulated in the project sampling and analysis plan (CH2M HILL, 1989d). Precision measurements based on these data reflect both field and laboratory variance. Laboratory duplicates were prepared in the laboratory and reflect only laboratory generated variance. Precision statements were calculated for each analyte of interest in each sample matrix using statistical procedures outlined in the project sampling and analysis plan (CH2M HILL, 1989d).

5.3.3 Representativeness

Representativeness is a measure of how closely the samples collected represent the population from which they were obtained. Representativeness is accomplished by: (1) choosing the number of samples, sampling locations, and sampling procedures that depict, as accurately and precisely as possible, the matrix and conditions being measured; (2) developing protocols for storage, preservation, and transportation that preserve the representativeness of the collected samples; (3) analyzing samples within the prescribed holding time; and, (4) using methods to document that protocols have been followed and that samples are properly identified so their integrity is maintained.

Laboratory sample handling, storage, and, documentation procedures used during the Area I Operable Unit Phase II RI followed the current U.S. EPA Contract Laboratory Program (CLP) protocol. Representativeness was addressed during the planning stages of the RI and is addressed in detail in the project sampling and analysis plan (CH2M HILL, 1989d).

One part of representativeness is quantifiable. Potential contamination resulting from sampling is bias which impacts representativeness. If contamination is significant, then the field samples may not be representative of what is measured. Quality control samples used to assess bias from contamination were field blanks of several type inserted into the sampling train at the prescribed frequency (CH2M HILL, 1989d)

5.3.4 Completeness

Completeness is the percentage of valid data compared to planned and collected data. Completeness was calculated following contract compliance and data validation and reduction. It was calculated as a percentage in two ways:

- Completeness = (# of valid samples/# of collected samples) x 100

- Completeness = (# of valid samples/# of planned samples) x 100

All sample data, except those flagged with an "R" in the project data bases, meet the criteria of being a valid sample data.

5.3.5 Comparability

Comparability of environmental data is achieved by adopting standard sampling and analysis procedures and through review of data from other sources. Comparability was assessed prior to any sample collection and was addressed in several planning documents. These included the project Field Sampling Plan (FSP-with appended Standard Operating Procedures), Contract Lab Program requests which specified laboratory methods and quality control criteria and the project QAPP. Methods used for Area I were consistent with the current standards of practice for the Superfund program.

5.4 SUMMARY TABLES FROM QUALITY ASSURANCE STATEMENTS

Summary quality assurance statements for surface water, groundwater, and soils/tailings are presented in Tables 5-1 through 5-12. These summary tables present information included in individual QA statements prepared for each analyte of interest in each sample matrix.

Accuracy statements presented in the tables were developed using blind field standard and laboratory matrix spike data. Presented values indicate that the data validator is 90% confident that the (value) % of the data lie within (value) ± (value) % of the reported value. The term "% of data" indicates that percent of data which fall within a 90% confidence level. Some quality control data were not used to calculate the mean recovery and its associated confidence interval because the quality control sample was identified as a statistical outlier or no quality control data, relating to specific field samples, were available. These data are not part of the calculated confidence interval.

The precision statements are interpreted in the same manner and are presented as " using blind field replicate data, the data validator is 90% confident that (value) % of the data lie within ± (value) % of the reported value." "Laboratory duplicates" is substituted for the phrase " blind field replicates," and is reported for laboratory precision.

Representativeness tables contain a reference as to the significance or insignificance of laboratory and field contamination for each parameter. Contamination was labelled "significant" if field blanks for each data set contained concentrations above the method detection limit. Natural samples were flagged with an appropriate qualifier if the

Table 5-1[illegible] Summary of quality assurance statements for analytes in surface water samples collected March 10, 1989. Area I on Phase II Remedial Investigation.

Analyte	Method	ACCURACY % of Data	ACCURACY (90% C.L.) Value	ACCURACY Based on	PRECISION % of Data	PRECISION (90% C.L.) Value	PRECISION Based on	REPRENTATIVENESS (Contamination) Field	REPRENTATIVENESS (Contamination) Lab	COMPLETENESS Valid Samples as % of Planned	COMPLETENESS Valid Samples as % of Collected
Hexavalent	7196	NK	NK	BFS	NK	NK	BFR	NS	NS	94%	94%
chromium		100%	95.0± 3.5	LSR	NK	NK	LD				
Nitrate	353.3	100%	9.6±28.1	BFS	NK	NK	BFR	NS	NS	90%	90%
		100%	95.7± 8.6	LSR	100%	109.0	LD				
Alkalinity	310.1	50%	103.0±NK*	BFS	50%	101.7[1]	BFR	NS	NS	84%	84%
		NK	NK	LSR	100%	8.23	LD				
Chloride	325.3	50%	95.9±NK*	BFS	100%	34.4	BFR	NS	NS	95%	95%
		100%	105.0±31.6	LSR	100%	39.5	LD				
Fluoride	340.2	50%	114.0±NK*	BFS	100%	72.5	BFR	NS	NS	95%	95%
		67%	103.3± 1.9	LSR	100%	22.8	LD				
Sulfate	375.4	50%	99.3±NK*	BFS	100%	12.0	BFR	NS	NS	95%	95%
		100%	107.5± 3.2	LSR	100%	11.6	LD				
TSS	160.2	NK	NK	BFS	100%	878.0	BFR	NS	NS	95%	95%
		NK	NK	LSR	100%	4.4	LD				

NOTES:

LD - Laboratory Duplicate
LSR - Laboratory Spike Recovery
BFS - Blind Field Standard
BFR - Blind Field Replicate

NK - Not Known
NS - Not Significant
* - Only one sample
1 - RPD (only one BFR result available)

Table 5 ummary of quality assurance statements for total metals an in surface water samples collected March 10. 1989. rea I on Phase II Remedial Investigation.

Analyte	Analysis Type	Instrumentation	ACCURACY % of Data	ACCURACY (90% C.L.) Value	ACCURACY Based on	PRECISION % of Data	PRECISION (90% C.L.) Value	PRECISION Based on	REPRESENTATIVENESS (Contamination) Field	REPRESENTATIVENESS (Contamination) Lab	COMPLETENESS Valid Samples as % of Planned	COMPLETENESS Valid Samples as % of Collected
Aluminum	Total	ICP	100	108.0±38.5	BFS	NK^1	NK^1	BFR	NK^1	NS	68	100
	Metals		100	85.8±67.9	LSR	100	12.6	LD				
Antimony	Total	ICP	NK^2	NK^2	BFS	NK^1	NK^1	BFR	NK^1	NS	68	100
	Metals		100	84.5±24.6	LSR	NK^2	NK^2	LD				
Arsenic	Total	FAA	100	84.5±28.5	BFS	NK^1	NK^1	BFR	NK^1	NS	63	92
	Metals		50	110.0±*	LSR	100	29.8	LD				
Cadmium	Total	FAA	100	98.4±15.5	BFS	NK^1	NK^1	BFR	NK^1	NS	63	92
	Metals		67	94.1±45.1	LSR	100	6.6	LD				
Chromium	Total	ICP	50	102±*	BFS	NK^1	NK^1	BFR	NK^1	NS	68	100
	Metals		100	85.0±26.5	LSR	100	176	LD				
Copper	Total	ICP	100	103±15.8	BFS	NK^1	NK^1	BFR	NK^1	NS	68	100
	Metals		50	86.8±*	LSR	100	16.1	LD				
Iron	Total	ICP	100	275±129	BFS	NK^1	NK^1	BFS	NK^1	NS	68	100
	Metals		50	70.0±*	LSR	100	72.8	LD				
Lead	Total	FAA	100	131±327	BFS	NK^1	NK^1	BFR	NK^1	S	68	100
	Metals		67	117.5±78.9	LSR	100	24.4	LD				
Manganese	Total	ICP	100	99.0±12.6	BFS	NK^1	NK^1	BFR	NK^1	NS	68	100
	Metals		100	71.0±56.8	LSR	100	16.9	LD				
Mercury	Total	CV	100	87.0±43.3	BFS	NK^1	NK^1	BFR	NK^1	NS	68	100
	Metals		100	113.3±15.6	LSR	67	94.2	LD				
Selenium	Total	FAA	100	48.4±78.2	BFS	NK^1	NK^1	BFR	NK^1	NS	63	92
	Metals		100	82.5±91.5	LSR	67	55.3	LD				
Zinc	Total	ICP	100	423±757	BFS	NK^1	NK^1	BFR	NK^1	NS	63	92
	Metals		100	52.0±328	LSR	100	12.3	LD				

NOTES:

ICP - Plasma Emission
FAA - Furnace AA
CV - Cold Vapor

BFS - Blind Field Standard
BFR - Blind Field Replicate
LSR - Laboratory Spike Replicate
LD - Laboratory Duplicate

NK - Not Known
NK^1 - Not known, no samples submitted or analyzed
NK^2 - Not known, some or all values < detection limit
* - less than required number of samples submitted or analyzed
NS - Not Significant

Table 5-3. Summary of quality assurance for total metals analyzed in surface water samples collected March 10,1989. Area I on Phase II Remedial Investigation.

Analyte	Analysis Type	Instrumentation	ACCURACY % of Data	ACCURACY (90% C.L.) Value	ACCURACY (90% C.L.) Based on	PRECISION % of Data	PRECISION (90% C.L.) Value	PRECISION (90% C.L.) Based on	REPRENTATIVENESS (Contamination) Field	REPRENTATIVENESS (Contamination) Lab	COMPLETENESS Valid Samples as % of Planned	COMPLETENESS Valid Samples as % of Collected
Calcium	Dissolved	ICP	100 NK[3]	102±4.1 NK[3]	BFS LSR	NK[1] 100	NK[1] 25.8	BFR LD	NK[1]	NS	68	100
Magnesium	Dissolved	ICP	100 NK[3]	18.6±9.5 NK[3]	BFS LSR	NK[1] 100	NK[1] 29.9	BFR LD	NK[1]	NS	68	100
Sodium	Dissolved	ICP	100 NK[3]	12.3±3.4 NK[3]	BFS LSR	NK[1] 100	NK[1] 34.7	BFR LD	NK[1]	NS	68	100
Potassium	Dissolved	ICP	NK[2] NK[3]	NK[2] NK[3]	BFS LSR	NK[1] 100	NK[1] 124	BFR LD	NK[1]	NS	68	100

NOTES:

LD - Laboratory Duplicate
LSR - Laboratory Spike Replicate
BFS - Blind Field Standard
BFR - Blind Field Replicate

NK[1] - Not known, no samples submitted or analyzed
NK[2] - Not known, some or all values < detection limit
NK[3] - Not known, no values reported

Table 5-4. Summary of quality assurance statemants for dissolved metals samples in samples collected March 10.1989. Area I on Phase II Remedial Investigation.

Analyte	Analysis Type	Instrumentation	ACCURACY % of Data	ACCURACY (90% C.L.) Value	ACCURACY Based on	PRECISION % of Data	PRECISION (90% C.L.) Value	PRECISION Based on	REPRENTATIVENESS (Contamination) Field	REPRENTATIVENESS (Contamination) Lab	COMPLETENESS Valid Samples as % of Planned	COMPLETENESS Valid Samples as % of Collected
Aluminum	Dissolved Metals	ICP	100 100	126±12.5 100.5±88.4	BFS LSR	NK^1 100	NK^1 382	BFR LD	NK^1	NS	68	100
Antimony	Dissolved Metals	ICP	NK^2 100	NK^2 95.0±7.6	BFS LSR	NK^1 NK^2	NK^1 NK^2	BFR LD	NK^1	NS	68	100
Arsenic	Dissolved Metals	FAA	100 100	97.3±3.2 82.7±11.6	BFS LSR	NK^1 100	NK^1 20.1	BFR LD	NK^1	NS	68	100
Cadmium	Dissolved Metals	FAA	100 NK^2	155±42.7 NK^2	BFS LSR	NK^1 100	NK^1 33	BFR LD	NK^1	NS	58	85
Chromium	Dissolved Metals	ICP	100 100	103±0.0 92.3±45.8	BFS LSR	NK^1 NK^2	NK^1 NK^2	BFR LD	NK^1	NS	68	100
Copper	Dissolved Metals	ICP	100 50	104±3.2 106±*	BFS LSR	NK^1 100	NK^1 95.5	BFR LD	NK^1	NS	68	100
Iron	Dissolved Metals	ICP	NK^2 100	NK^2 94.8±48.6	BFS LSR	NK^1 100	NK^1 102	BFR LD	NK^1	NS	68	100
Lead	Dissolved Metals	FAA	100 100	98.5±9.8 98.3±6.4	BFS LSR	NK^1 100	NK^1 32.6	BFR LD	NK^1	NS	68	100
Manganese	Dissolved Metals	ICP	100 100	104±9.6 76.3±116	BFS LSR	NK^1 100	NK^1 35.7	BFR LD	NK^1	NS	68	100
Mercury	Dissolved Metals	CV	100 100	103.9±19.2 114.7±9.3	BFS LSR	NK^1 NK^2	NK^1 NK^2	BFR LD	NK^1	NS	68	100
Selenium	Dissolved Metals	FAA	100 100	112.5±23.5 99.3±11.5	BFS LSR	NK^1 100	NK^1 116	BFR LD	NK^1	NS	68	100
Zinc	Dissolved Metals	ICP	100 50	109±28.4 100±*	BFS LSR	NK^1 100	NK^1 40.3	BFR LD	NK^1	NS	68	100

NOTES:

LD - Laboratory Duplicate
LSR - Laboratory Spike Recovery
BFS - Blind Field Standard
BFR - Blind Field Replicate

NK - Not Known
NS - Not Significant

NK^1 - Not known, no samples submitted or analyzed
NK^2 - Not known, some or all values < detection limit
NK^3 - Not known, no values reported

Table 5- ummary of quality assurance statements for acid-soluble met alyzed in surface water samples collected March 10, 1989. Area I on Phase II Remedial Investigation.

Analyte	Analysis Type	Instrumentation	ACCURACY % of Data	ACCURACY (90% C.L.) Value	ACCURACY Based on	PRECISION % of Data	PRECISION (90% C.L.) Value	PRECISION Based on	REPRESENTATIVENESS (Contamination) Field	REPRESENTATIVENESS (Contamination) Lab	COMPLETENESS Valid Samples as % of Planned	COMPLETENESS Valid Samples as % of Collected
Aluminum	Acid	ICP	100	120±125	BFS	100%	19.9	BFR	NS	S	100	100
	Soluble		100	97.3±109	LSR	100%	31.2	LD				
Antimony	Acid	ICP	NK^2	NK^2	BFS	NK^2	NK^2	BFR	NS	NS	100	100
	Soluble		100	96.3±9.5	LSR	NK^2	NK^2	LD				
Arsenic	Acid	FAA	100	92.5±15.8	BFS	100%	84.7	BFR	NS	NS	100	100
	Soluble		100	113.7± 27.7	LSR	100%	6.8	LD				
Cadmium	Acid	FAA	NK^2	NK^2	BFS	100%	215.1	BFR	NS	NS	68	68
	Soluble		100	118.5±3.2	LSR	100%	25.1	LD				
Chromium	Acid	ICP	100	115±85	BFS	100%	72.1	BFR	NS	NS	100	100
	Soluble		100	104.5±12.5	LSR	NK^2	NK^2	LD				
Copper	Acid	ICP	100	108±63	BFS	100%	18.9	BFR	NS	NS	100	100
	Soluble		100	-10.6±-74.6**	LSR	100%	48.9	LD				
Iron	Acid	ICP	100	67.0±15.6	BFS	100%	11.1	BFR	NS	NS	100	100
	Soluble		100	91.9±189	LSR	100%	99.3	LD				
Lead	Acid	FAA	100	100±28.4	BFS	100%	189.6	BFR	NS	NS	100	100
	Soluble		100	94.0±1.7	LSR	100%	19.7	LD				
Manganese	Acid	ICP	100	112±63	BFS	100%	15.1	BFR	NS	NS	100	100
	Soluble		100	92.4±154	LSR	100%	56.7	LD				
Mercury	Acid	CV	100	116.0±50.9	BFS	NK^2	NK^2	BFR	NS	NS	100	100
	Soluble		100	111.7±7.8	LSR	NK*	NK*	LD				
Selenium	Acid	FAA	100	116±63	BFS	NK^2	NK^2	BFR	NS	NS	100	100
	Soluble		100	81.0±36.6	LSR	NK^2	NK^2	LD				
Zinc	Acid	ICP	100	110±35	BFS	100%	20.1	BFR	NS	NS	100	100
	Soluble		100	105.8±36.6	LSR	100%	142	LD				

NOTES:

ICP - Plasma Emission
FAA - Furnace AA

BFS - Blind Field Standard
BFR - Blind Field Replicate
LSR - Laboratory Spike Replicate
LD - Laboratory Duplicate
CV - Cold Vapor

NK^1 - Not known, no samples submitted or analyzed
NK^2 - Not known, some or all values < detection limit
* - less than required number of samples submitted or analyzed
** - One sample was >4 x spike value
NS - Not Significant

Table 5-[illegible]. Summary of quality assurance statements for analytes in gr[illegible]ater samples collected August 15-25, 1989. Area I on Phase II Remedial Investigation.

		ACCURACY			PRECISION			REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
		% of	(90% C.L.)		% of	(90% C.L.)					
Analyte	Method	Data	Value	Based on	Data	Value	Based on	Field	Lab	Planned	Collected
Alkalinity	310.1	100%	99.0±13.1%	BFS	66%	± 4.4%	BFR	S	NS	91%	100%
		--	NR	LSR	80%	± 1.5%	LD				
Chloride	300.0	100%	96.1±63.1%	BFS	100%	± 0.5%	BFR	NS	NS	91%	100%
		100%	99.1± 8.0%	LSR	80%	± 5.2%	LD				
Fluoride	300.0	100%	119.4±25.3%	BFS	100%	±24.6%	BFS	NS	NS	91%	100%
		100%	101.8± 4.4%	LSR	80%	± 5.8%	LD				
Nitrate + Nitrite-N	300.0	--	Unknown*	BFS	66%	± 4.8%	BFS	NS	NS	87%	91%
		100%	100.9± 1.1%	LSR	60%	± 1.5%	LD				
Sulfate	300.0	100%	104.3± 2.0%	BFS	100%	± 0.9%	BFS	NS	NS	91%	100%
		100%	103.2± 0.8%	LSR	80%	± 1.8%	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate
NR - Not Required

NK - Not Known
NS - Not Significant
S - Significant
* - See text for explanation

Table 5-7. Summary of quality assurance statements for dissolved metals in groundwater samples collected August 15-25, 1989. Area I on Phase II Remedial Investigation.

		ACCURACY	(90% C.L.)		PRECISION	(90% C.L.)		REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
Analyte	Method	% of Data	Value	Based on	% of Data	Value	Based on	Field	Lab	Planned	Collected
Aluminum	200.7	100%	119.3±12.6%	BFS	33%	± 0.9%RPD*	BFR	NS	S	90%	91%
		75%	96.9± 7.4%	LSR	75%	± 20.6%	LD				
Antimony	200.7	100%	118.3±30.1%	BFS	--	NK	BFR	NS	NS	90%	91%
		100%	107.1±12.6%	LSR	--	NK	LD				
Arsenic	206.2	100%	90.1±17.0%	BFS	66%	±352.0%	BFR	NS	NS	90%	91%
		100%	103.0±29.8%	LSR	75%	± 61.6%	LD				
Cadmium	200.7	100%	109.6± 5.2%	BFS	100%	± 26.7%	BFR	NS	NS	90%	91%
		75%	105.4±11.1%	LSR	66%	± 26.8%	LD				
	213.2	100%	99.4±17.4%	LSR	100%	± 23.6%	LD	S	NS		
Chromium	200.7	100%	104.8± 3.9%	BFS	--	NK	BFR	S	S	90%	91%
		100%	93.7± 8.5%	LSR	--	NK	LD				
Copper	200.7	100%	103.3± 3.4%	BFS	100%	± 28.4%	BFR	S	NS	90%	91%
		100%	97.9± 3.7%	LSR	100%	± 8.9%	LD				
Iron	200.7	100%	111.6±17.7%	BFS	66%	± 32.2%	BFR	S	S	90%	91%
		50%	104.3± 1.8%	LSR	100%	± 7.1%	LD				
Lead	239.2	100%	112.9±20.6%	BFS	66%	±305.0%	BFR	S	NS	90%	91%
		75%	116.5±21.9%	LSR	25%	± 4.0%RPD*	LD				
Manganese	200.7	100%	111.9±20.4%	BFS	100%	± 11.8%	BFR	S	S	90%	91%
		25%	98.3%R*	LSR	100%	± 2.9%	LD				
Mercury	245.1	100%	89.2±10.3%	BFR	--	NK	BFR	S	NS	90%	91%
		100%	102.1±12.1%	LSR	25%	± 0.0%RPD*	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate

NK - Not Known-values leass than IDL
NS - Not Significant (blank levels <IDL)
S - Significant (blank level >IDL)

*%RPD and %R are given when N=1

Table 5-7. Continued.

		ACCURACY (90% C.L.)			PRECISION (90% C.L.)			REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
Analyte	Method	% of Data	Value	Based on	% of Data	Value	Based on	Field	Lab	Planned	Collected
Selenium	270.2	100%	82.3±19.9%	BFS	--	NK	BFR	S	NS	90%	91%
		100%	68.7±52.5%	LSR	25%	± 11.0%RPD*	LD				
Zinc	200.7	100%	92.3± 6.1%	BFS	100%	± 19.1%	BFR	S	NS	90%	91%
		50%	100.3± 9.8%	LSR	100%	± 2.4%	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate

NK - Not Known-values leass than IDL
NS - Not Significant (blank levels <IDL)
S - Significant (blank level >IDL)

*%RPD and %R are given when N=1

Table 5-8. Summary of quality assurance statements for total metals in impounded tailings samples collected June 19 to July 6, 1989.- Area I on Phase II Remedial Investigation.

		ACCURACY			PRECISION			REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
		% of	(90% C.L.)		% of	(90% C.L.)					
Analyte	Method	Data	Value	Based on	Data	Value	Based on	Field	Lab	Planned	Collected
Aluminum	200.7	100%	24.2± 2.3%	BFS	100%	± 9.5%	BFR	NS	NS	93%	98%
		--	NR	LSR	86%	± 1.7%	LD				
Antimony	200.7	100%	13.4± 1.8%	BFS	50%	±34.2	BFR	NS	NS	79%	83%
		100%	47.3± 9.4%	LSR	57%	±16.4	LD				
Arsenic	206.2	86%	72.2± 3.5%	BFS	100%	± 9.8%	BFR	NS	NS	93%	98%
		14%	89.8%R*	LSR	86%	± 5.9%	LD				
Beryllium	200.7	86%	90.0± 0.7%	BFS	17%	±19.4%RPD*	BFR	NS	NS	93%	98%
		100%	92.1± 3.9%	LSR	71%	±15.7%	LD				
Cadmium	200.7	86%	82.6± 0.8%	BFS	50%	±18.9%	BFR	NS	NS	90%	94%
		86%	70.8±30.0%	LSR	43%	±14.6%	LD				
Chromium	200.7	86%	78.9± 1.4%	BFS	83%	±17.6%	BFR	NS	NS	83%	88%
		86%	96.2± 7.7%	LSR	71%	± 9.4%	LD				
Copper	200.7	86%	79.4± 0.4%	BFS	83%	± 6.6%	BFR	NS	NS	93%	98%
		29%	75.4±18.0%	LSR	86%	± 4.4%	LD				
Iron	200.7	--	NK	BFS	100%	± 9.5%	BFR	NS	NS	93%	98%
		--	NR	LSR	100%	± 3.4%	LD				
Lead	239.2	100%	88.2± 5.4%	BFS	83%	± 8.8%	BFR	NS	NS	93%	98%
		43%	46.3±19.1%	LSR	100%	±14.4%	LD				
Manganese	200.7	86%	92.8± 0.8%	BFS	100%	± 6.3%	BFR	NS	NS	93%	98%
		14%	99.6%R*	LSR	100%	± 4.4%	LD				
Mercury	245.5	100%	197.2± 9.4%	BFS	33%	±50.5%	BFR	NS	NS	93%	98%
		100%	123.4±19.5%	LSR	71%	±13.9%	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate

NK - Not Known-values leass than IDL
NS - Not Significant (blank levels <IDL)
NR - Not Required under CLP SOW

*%RPD and %R are given when N=1

Table 5-8. Continued.

		ACCURACY			PRECISION			REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
		% of	(90% C.L.)		% of	(90% C.L.)					
Analyte	Method	Data	Value	Based on	Data	Value	Based on	Field	Lab	Planned	Collected
Selenium	270.2	100%	113.7± 9.8%	BFS	--	NK	BFR	NS	NS	93%	98%
		100%	68.2±15.4%	LSR	14%	±63.6%RPD*	LD				
Zinc	200.7	100%	19.9± 1.5%	BFS	83%	± 9.5%	BFR	NS	NS	93%	98%
		43%	77.8±27.5%	LSR	100%	± 4.5%	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate

*%RPD and %R are given when N=1

NK - Not Known-values leass than IDL
NS - Not Significant (blank levels <IDL)
NR - Not Required under CLP SOW

Table 5-9. Summary of quality assurance statements for total metals in dispersed tailings samples collected June 13 to August 4, 1989. Area I on Phase II Remedial Investiation.

		ACCURACY			PRECISION			REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
Analyte	Method	% of Data	Value (90% C.L.)	Based on	% of Data	Value (90% C.L.)	Based on	Field	Lab	Planned	Collected
Aluminum	200.7	100%	27.1± 6.1%	BFS	100%	± 5.8%	BFR	NS	NS	106%	100%
		--	NR	LSR	100%	± 7.2%	LD				
Antimony	200.7	88%	11.0± 3.8%	BFS	86%	±18.5%	BFR	NS	NS	105%	99%
		100%	38.1± 9.9%	LSR	67%	±30.2%	LD				
Arsenic	206.2	88%	63.3± 2.1%	BFS	86%	± 2.9%	BFR	NS	NS	106%	100%
		78%	93.7± 2.6%	LSR	100%	± 6.8%	LD				
Beryllium	200.7	100%	85.5± 13.0%	BFS	57%	±22.5%	BFR	NS	NS	106%	100%
		100%	87.9± 2.4%	LSR	67%	±14.3%	LD				
Cadmium	200.7	100%	83.2± 13.3%	BFS	57%	± 3.4%	BFR	NS	NS	106%	100%
		100%	99.4± 4.7%	LSR	100%	±12.6%	LD				
Chromium	200.7	100%	78.5± 12.1%	BFS	86%	±11.5%	BFR	NS	NS	104%	98%
		89%	99.0± 3.1%	LSR	67%	± 6.5%	LD				
Copper	200.7	100%	77.0± 12.5%	BFS	100%	± 4.9%	BFR	NS	NS	106%	100%
		33%	102.5± 32.1%	LSR	89%	± 2.7%	LD				
Iron	200.7	--	NK	BFS	100%	± 4.2%	BFR	NS	NS	106%	100%
		--	NR	LSR	100%	± 3.4%	LD				
Lead	239.2	100%	80.3± 12.8%	BFS	100%	± 8.3%	BFR	NS	NS	106%	100%
		22%	52.8±389.2%	LSR	89%	± 8.8%	LD				
Manganese	200.7	100%	91.6± 14.6%	BFS	100%	± 4.5%	BFR	NS	NS	106%	100%
		33%	94.7± 20.1%	LSR	78%	± 7.1%	LD				
Mercury	245.5	100%	129.3± 95.8%	BFS	86%	±10.6%	BFR	NS	NS	106%	100%
		89%	116.4± 28.6%	LSR	89%	±18.0%	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate

NK - Not Known
NS - Not Significant (blank levels <IDL)
NR - Not Required under CLP SOW

*XR is given when N=1

Table 5-9. Continued.

		ACCURACY			PRECISION			REPRESENTATIVENESS (Contamination)		COMPLETENESS Valid Samples as % of	
		% of	(90% C.L.)		% of	(90% C.L.)					
Analyte	Method	Data	Value	Based on	Data	Value	Based on	Field	Lab	Planned	Collected
Selenium	270.2	88%	88.5± 9.9%	BFS	86%	±24.3%	BFR	NS	NS	104%	98%
		100%	46.2± 32.8%	LSR	78%	±18.4%	LD				
Zinc	200.7	100%	19.8± 2.4%	BFS	100%	± 7.9%	BFR	NS	NS	106%	100%
		11%	79.3%R*	LSR	100%	± 6.5%	LD				

NOTES:

BFS - Blind Field Standard
LSR - Laboratory Spike Replicate
BFR - Blind Field Replicate
LD - Laboratory Duplicate

*%R is given when N=1

NK - Not Known
NS - Not Significant (blank levels <IDL)
NR - Not Required under CLP SOW

Table 5-10. Summary of Blind Field Standard Recovery for Organics in Dispersed Tailings. Area I Phase II Remedial Investigation.

Compound Name	Expected Value (μg/Kg)*	Expected Range (μg/Kg)*	Reported Values and % of Expected Value HC 419	%R	HC 420	%R	Average %R
1,1,2-Trichloroethane	96.1	49-130	100	104	95	99	102
Carbon tetrachloride	30.7	19-36	28	91	28	91	91
Chloroform	72.5	45-88	68	94	67	92	93
2-Butanone	165	24-290	290	176	240 E	145	161
Methylene Chloride	20.4	7.1-43	27 B	132	26 B	127	130
Tetrachloroethene	104	56-135	95	91	92	88	90
Trichloroethene	13.9	7.9-19	13	94	13	94	94
Total Xylenes	43.9	13-70	46	105	44	100	103
Nitrobenzene	9410	2800-15000	3500	37	5000	53	45
Isophorone	10500	2200-12000	3800	36	5700	54	45
1,2,4-Trichlorobenzene	7460	2800-10000	3100	42	4300	58	50
Napthalene	8060	2800-11000	3500	43	4300	53	48
Acenaphthene	4200	900-5600	1300	31	1700	40	36
Dibenzofuran	2110	630-3200	1100	52	1500	71	62
Benzo(b) Fluoranthene	3140	650-4900	1000	32	2600	83	58
Bis(2-ethylhexyl)phthalate	3930	1100-6200	2100 B	53	3100 B	79	66
2-Methylphenol	4360	1100-5500	660	15	380 J	9	12
2,4-Dimethylphenol	2480	690-2900	660	27	660	27	27
2,4-Dinitrophenol	9590	330-12000	620 J	6	1400 J	15	11
Pentachlorophenol	2490	350-4300	1400 J	56	1600 J	64	60
4,4[1]-DDT	233	71-330	150	64	160	69	67
4,4[1]-DDE	121	35-170	150	124	160	132	128
Dieldrin	258	90-420	160	62	270	105	84

* Blind Field Standard: Organics in Soil, Lot No. 302. ERA, Arvada, Colorado.

Validation Code Explanation:

B = value greater than or equal to instrument detection limit but less then contract detection limit.
E = value estimated or not reported due to interference
J = value useful only as estimate because quality control criteria were not met

Table 5-11. Summary of Blind Field Replicate Data for Organics in Dispersed Tailings. Area I Phase II Remedial Investigation.

Compound Name	Natural Sample (HC 410) $\mu g/Kg$	Field Replicate (HC 411) $\mu g/Kg$	% RPD	Natural Sample (HC 416) $\mu g/Kg$	Field Replicate (HC 418) $\mu g/Kg$	% RPD	Average % RPD
Methylene Chloride	4 BJ	4 BJ	0.0	6 B	<IDL	--	0.0
Di-n-butylphthalate	440 BJ	460 BJ	4.4	1200 B	810 B	38.8	21.6
Bis(2-ethylhexyl)phthalate	210 BJ	160 BJ	27.0	480 BJ	410 BJ	15.7	21.4
Acetone				<IDL	3 J	--	--

Validation Code Explanation:

B = value greater than or equal to instrument detection limit but less then contract detection limit.
E = value estimated or not reported due to interference
J = value useful only as estimate because quality control criteria were not met

Table 5-12. Summary of Field Blanks Data for Organics in Dispersed Tailings. Area I Phase II Remedial Investigation

Compound Name	Trip Blank (HC 404) µg/Kg	Water Blanks (µg/L) HC 407	HC 417	Bottle Blanks (µg/L) HC 409	HC 414
Methylene Chloride	38 BJ	8	6	8	8
2-Butanone	39 J			4 J	
Di-n-butylphthalate	250 BJ		38 BJ	61 BJ	39 BJ
Bis(2-ethylhexyl)phthalate	130 BJ	39 BJ	27 BJ	37 BJ	21 BJ
Chloroform		1 J	9	11	12
Toluene		2 J		2 J	2 J
1,1,1-Trichloroethane				1 J	1 J
Bromodichloromethane				1 J	1 J
2-Hexanone				1 J	1 J

Validation Code Explanation:
B = value greater than or equal to instrument detection limit but less then contract detection limit.
E = value estimated or not reported due to interference
J = value useful only as estimate because quality control criteria were not met

concentration of the natural sample was less than five times the highest blank value for a given data set containing blank samples above method detection limits for a given parameter.

All data have been independently verified using methods and procedures referenced in earlier sections. Due to the large volume of QC data necessary to validate chemical data, only summary tables have been presented in this report. All QC and back-up data used in the validation process data are filed in the administrative record.

5.5 QUALITY CONTROL OF FIELD MEASUREMENTS

Details regarding field procedures and methods for observations and field measurements are described in the project sampling and analysis plan (CH2M HILL, 1989d). Standard operating procedures for all field activities were appended to the sampling and analysis plan and contain all QC requirements for field measurements.

Field measurements obtained while water samples were collected included streamflow (surface water only), water temperature, pH, specific conductance (SC), Eh (groundwater only). Assessment of the precision of these field measurements was based on the field replicate determinations. The accuracy of these field measurements was based on standard operating procedures, instrument calibration in the field, blind field standards for pH and SC, and the professional judgment of the field sampling teams.

Eh (redox potential) measurements completed during this investigation do not accurately reflect the true redox potential of media measured. Reported values for Eh are actually uncorrected platinum electrode readings which provide an indication of oxidizing or reducing conditions of the medium measured.

SECTION 6.0 CONCLUSIONS

6.0 CONCLUSIONS

Three general types of field investigations were performed during the Area I Operable Unit Phase II Remedial Investigation. These included studies of surface water, groundwater, and tailings and contaminated soils. Data were not collected during the Phase II Remedial Investigation to directly characterize air quality in Area I.

Data collected during the Phase II Remedial Investigation in Area I provide a basis from which remedial alternatives can be evaluated during the subsequent feasibility study for the site. In addition, these data can be used to complete the site public health and environmental assessment. Phase II Remedial Investigation data supplement data generated during the Phase I Remedial Investigation for the Silver Bow Creek CERCLA site (MultiTech, 1987). Other recently collected environmental data for the operable unit have been gathered by ARCO Coal Company, Montana Bureau of Mines and Geology, and the U.S. Geological Survey. These data are not presented in this report.

The primary contaminants of concern in the Area I Operable Unit are metals, particularly copper, zinc, arsenic, cadmium, lead, and iron. Other specific contaminants of concern may be identified during developement of the public health and environmental assessment. These contaminants are contained in soils, tailings, and mine wastes within Area I and impact both surface water and groundwater resources in the operable unit.

For purposes of discussion in this section of the report, areas or soil units within Area I which exhibited metals concentrations one to two orders of magnitude above adjacent and subjacent areas or soil units and/or were easily solubilized in water are considered metals source areas. The primary metals source areas and soil units in Area I during the Phase II Remedial Investigation include the following:

- Historic Parrott Smelter area -- includes the area in the vicinity of the City-County shop complex to near Harrison Avenue. Metals source materials include subsurface tailings, slag, organic materials, and fluvial-tailings mixed material. Most of these materials have been covered in this portion of the study area with waste rock and other types of fill material. The most prominent impact resulting from this metals source area is on the quality of water in the groundwater system within and beneath these materials.

- Lower Metro Storm Drain area -- includes stream deposited tailings mixed with fluvial sediments. Although much of this material in the portion of the study area has been filled over with landfill debris, certain areas remain exposed and are subject to erosion into the Metro Storm Drain. In addition, these materials are generally present at or just above the local groundwater level and may serve as a source of metals to the groundwater system. Metals concentrations in this material are relatively lower than those measured in other source areas.

- Historic Butte Reduction Works tailing impoundments -- includes the two historic tailing cells associated with this facility, the area east of the tailing cells, and the area in the vicinity of the Butte Sewage Treatment Plant. Metals source materials include tailings, slag, and underlying native soils. The primary impacts from this source area are realized in the groundwater system within and underlying these materials and in the quality of runoff water moving overland across the area.

- Colorado Tailings -- includes the exposed 40 acre tailings deposit and a small parcel of property northwest of the main deposit, across Silver Bow Creek. Source materials generally include tailings and peat. Impacts of this source area on the environment include groundwater degradation, surface runoff degradation, and possibly air quality deterioration.

- Railroad Ballast -- includes operating and abandoned railroad beds and ballast located near the Butte Reduction Works tailing impoundments and the manganese stockpile area. The ballast is comprised of various grades and types of fill material, some of which appears to be mineralized. Impacts from this metals source area are primarily on surface runoff quality and possibly on groundwater quality.

- Tailings beneath Slag Walls -- these deposits are located in the manganese stockpile area and appear to have been sluiced to their present location prior to construction of overlying slag walls. Metals in these deposits are some of the highest measured in soils and tailings sampled within the operable unit. Because

a significant portion of the metals in these materials are soluble in water, impacts to both surface runoff quality and groundwater probably occur.

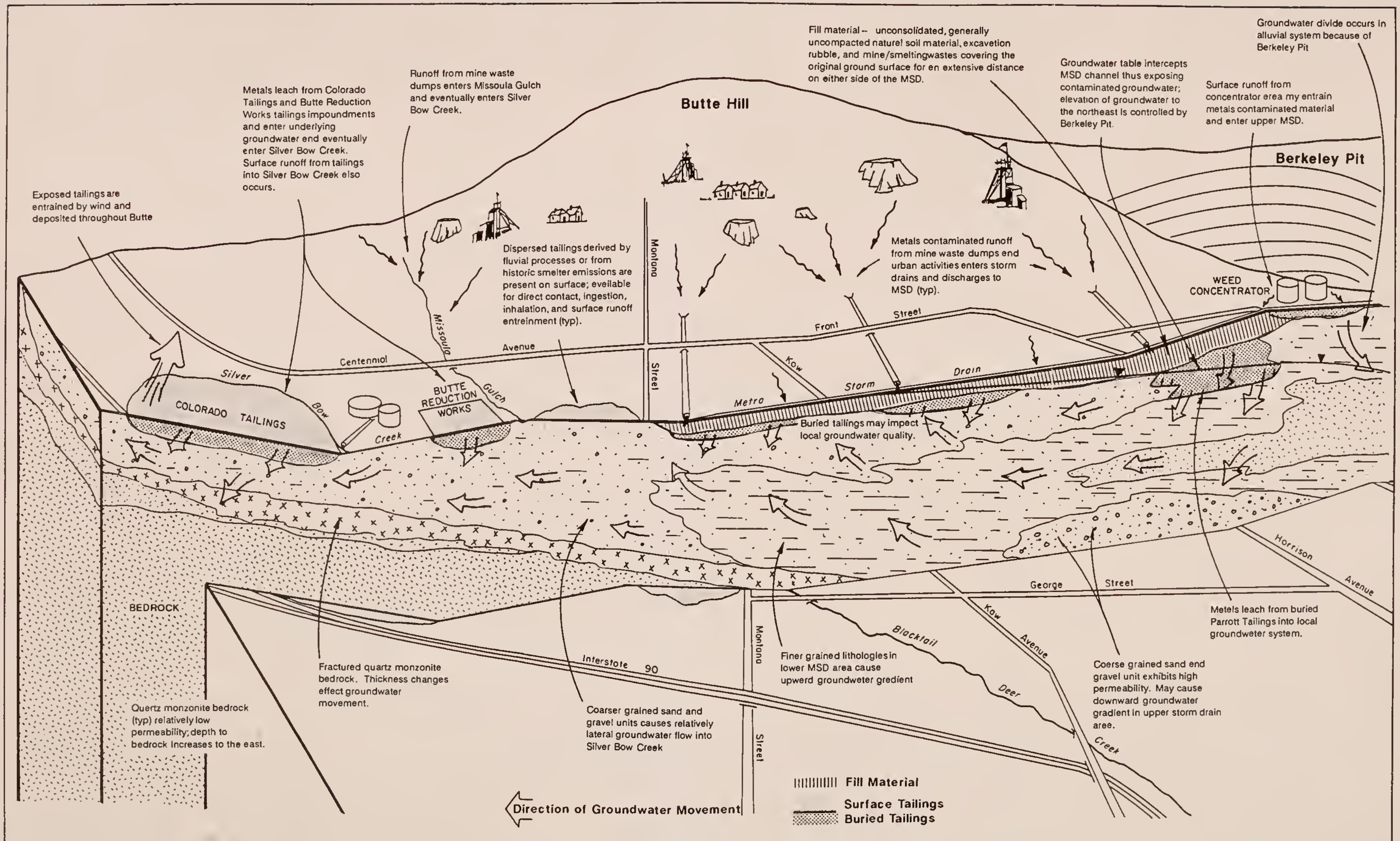
Other potential metals contaminant source areas are located adjacent to the Area I Operable Unit. These sources are located on Butte Hill and generally include mine waste dumps and tailing deposits; the U.S. EPA is currently evaluating these potential sources of metals contamination.

The primary pathways of metals contaminant movement in Area I include surface runoff, precipitation infiltration, groundwater movement, and airborne transmission. The latter pathway of contaminant movement was not directly evaluated during the Phase II Remedial Investigation. Figure 6-1 conceptually illustrates pathways of contaminant movement in the Area I Operable Unit.

Data collected during the Phase II Remedial Investigation indicate that the majority of metals transported by snowmelt runoff in the Butte area is derived from areas outside of Area I, primarily on Butte Hill. However, several areas within Area I (e.g. Colorado Tailings) also represent sources of metals contamination to Silver Bow Creek during runoff events. The most prominent sources of metals during surface runoff events are located in areas which drain to the Metro Storm Drain. Other areas which supply a measurable impact on metals concentrations and loads in Silver Bow Creek include Missoula Gulch and other storm outfalls which directly enter Silver Bow Creek from the north side.

Metals concentrations in snowmelt runoff at several locations in Area I exceed both chronic and acute ambient water quality criteria, particularly for copper, zinc, cadmium, and lead, and exceed primary drinking water standards for cadmium, arsenic, and lead. The input of Blacktail Creek to Silver Bow Creek during both high and low flow conditions serves as a source of dilution to the operable unit's surface water system. Blacktail Creek, however, also exceeded chronic aquatic water quality criteria for cadmium and both chronic and acute aquatic water quality criteria for lead, copper, and zinc during the snowmelt runoff sampling event completed during the Phase II Remedial Investigation.

Precipitation infiltration was not directly characterized during the Phase II Remedial Investigation in Area I. However, this pathway of metals contaminant movement within the



Conceptual Model of Contaminant Pathways

Area I Operable Unit Phase II Remedial Investigation

FIGURE 6-1

operable unit probably occurs because of the presence of relatively coarse grained sediments in certain portions of the site, particularly in the vicinity of mine and mill tailings. Infiltration of precipitation would result in leaching of metals from metals source areas into the underlying groundwater system. The relative impact of this pathway of metals contaminant movement in Area I is unknown.

Groundwater transports metals contaminants in Area I which are derived through two primary mechanisms. These include transport of metals produced through leaching of overlying metals source materials and inundation of source materials through groundwater level change. Once metals enter the area's groundwater system, they move within the system in response to horizontal and vertical groundwater gradients reacting with mineral components in the aquifer that attenuate their transport.

For purposes of this report, "metals-contaminated groundwater" refers to groundwater which exceeds primary drinking water standards and to copper and zinc concentrations in groundwater which are an order of magnitude greater than adjacent groundwater quality.

Three general source areas of metals-contaminated groundwater are present within Area I. These include the City-County shop complex area in the upper Metro Storm Drain vicinity and the historic Butte Reduction Works tailing impoundments area and Colorado Tailings located near the lower end of the operable unit. Groundwater in these areas exceeds primary drinking water standards for arsenic, cadmium, and lead. Metals concentrations are highest proximal to these source areas and generally decrease both laterally away from the sources and also with depth.

Shallow groundwater in the upper portion of the operable unit intercepts the Metro Storm Drain near Harrison Avenue and is expressed as surface flow through the lower portion of the drain. A groundwater recharge area was identified near the head of the Metro Storm Drain. A component of the groundwater system moves downward in this area, moving metals contaminants to depths of approximately 150 feet below ground surface. A relatively higher permeability zone identified at depths greater than 200 feet below ground surface may contribute to the measured downward gradient in this area.

A groundwater divide is present in the alluvial groundwater system near Continental Drive at the upper end of the Metro Storm Drain. Groundwater north of this divide moves toward the Berkeley Pit; groundwater south of the divide moves to the southeast, parallel to the Metro Storm Drain. The horizontal groundwater gradient is subtle in the immediate vicinity of the divide and increases in magnitude toward the Berkeley Pit and toward the middle reaches of the Metro Storm Drain. The groundwater divide occurs in an area of metals-contaminated groundwater. Therefore, a sizable component of metals-contaminated groundwater is currently moving toward the Berkeley Pit and does not directly impact groundwater resources in Area I.

If water levels in the Berkeley Pit are allowed to rise into the alluvial material along the southern and eastern portions of the pit, it is probable the groundwater divide in the upper Metro Storm Drain area will migrate toward the pit. This condition would allow a larger component of the metals-laden groundwater in this area to move to the southwest, parallel to the Metro Storm Drain. The location at which groundwater intercepts the base of the Metro Storm Drain would also probably migrate up the drain as the groundwater divide moves toward the Berkeley Pit.

The lower portion of the Metro Storm Drain area exhibits an upward groundwater gradient, characteristic of a groundwater discharge area. Aquifer material encountered at depth in this portion of the operable unit is relatively less permeable than that identified at depth in the upper Metro Storm Drain area. Lateral decreases in permeability may explain the cause of the upward groundwater gradient in the lower Metro Storm Drain area. This phenomenon serves to limit the vertical extent of metals contamination in groundwater in the lower Metro Storm Drain area and facilitates groundwater discharge to the Metro Storm Drain.

Metals-contaminated groundwater in the vicinity of the historic Butte Reduction Works tailing impoundments is generally present within the upper 10 feet of the alluvial groundwater system. Groundwater in this portion of the operable unit generally moves horizontally and discharges into Silver Bow Creek. The impact of discharge of metals-contaminated groundwater into Silver Bow Creek is realized in the stream most prominently during low flow and baseflow conditions.

Shallow groundwater in the Colorado Tailings area generally moves from southeast to northwest across the deposit, eventually discharging to Silver Bow Creek. Groundwater quality is degraded along the groundwater flow path; highest metals concentrations in the shallow groundwater system occur in the northwest corner of the tailings. Metals-contaminated groundwater is also present northwest of the Colorado Tailings, across Silver Bow Creek. A portion of the Colorado Tailings truncated from the main deposit through rechannelization of Silver Bow Creek is the probable source of metals in groundwater in this area.

The vertical component to groundwater movement in the Colorado Tailings area appears to directly affect the occurrence of metals-contaminated groundwater in the underlying bedrock groundwater system. Most metals concentrations decrease with depth in the alluvial groundwater system beneath the Colorado Tailings. However, metals concentrations in the underlying bedrock groundwater system in the central and western portions of the Colorado Tailings are relatively higher than in either shallower or deeper portions of the alluvial system.

The hydraulics of groundwater movement in the Colorado Tailings area may serve to transport shallow sources of metals downward causing metals contamination in the bedrock groundwater system. Alternatively, an unidentified metals source may cause metals contamination of groundwater in the bedrock system underlying portions of the Colorado Tailings. The vertical extent of metals-contaminated groundwater in the bedrock system underlying the Colorado Tailings was not determined during this study.

A relatively strong downward groundwater gradient was measured near the southern and southeastern portions of the Colorado Tailings and to the east of the deposit. Upward groundwater gradients were identified near the west end of the Colorado Tailings and west of the deposit in the Silver Bow Creek alluvium. The upward groundwater gradient identified in this portion of the operable unit may be caused by a decrease in thickness of the alluvial groundwater system.

Certain metals, particularly arsenic and iron, appear to be transported via the shallow groundwater system associated with the Silver Bow Creek alluvium from the Colorado Tailings area out of the operable unit to the west. It is unknown if the source of the metals

measured in the Silver Bow Creek alluvial aquifer are associated solely with the Colorado Tailings source areas or if additional metals sources are present along Silver Bow Creek.

The greatest impact of metals-contaminated groundwater discharge from the Colorado Tailings area to Silver Bow Creek is also realized in the stream during low flow and baseflow conditions. The magnitude of metals concentrations and metals loads transported by surface runoff during higher flow conditions tends to mask the impact of contaminated groundwater input to Silver Bow Creek.

The ultimate recipient of metals transported via the various pathways described above is Silver Bow Creek. During surface runoff events produced either by precipitation or snowmelt, entrainment and solubilization of metals present in the numerous source areas both within and outside of Area I measurably impact the quality of water in Silver Bow Creek. Runoff causes exceedances of both chronic and acute aquatic water quality standards for copper, zinc, lead, and cadmium. Exceedances of primary drinking water standards for arsenic, cadmium, and lead also occur during runoff events.

During non-runoff conditions, input of metals-laden groundwater derived primarily from the Parrott Tailings area, the Butte Reduction Works tailings impoundment area, and the Colorado Tailings causes exceedances of both chronic and acute aquatic water quality criteria for copper, zinc, and cadmium in Silver Bow Creek, particularly during low flow and baseflow conditions in the stream. In addition, approximately 400 acres of the alluvial groundwater system in Area I also exceed federal primary drinking water standards for arsenic, cadmium, or lead and thus are not available as a potable water supply.

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7.0 REFERENCES CITED

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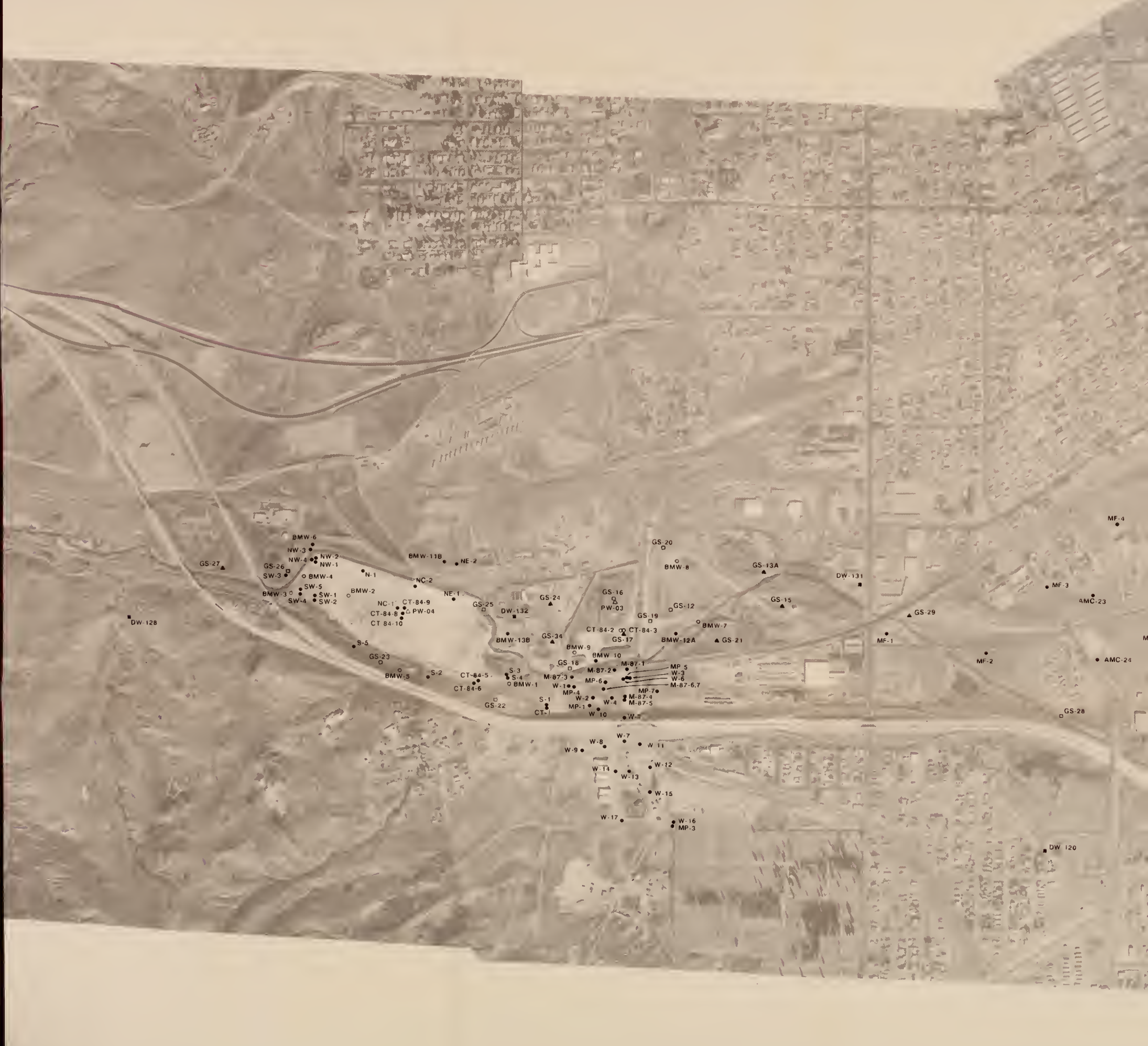
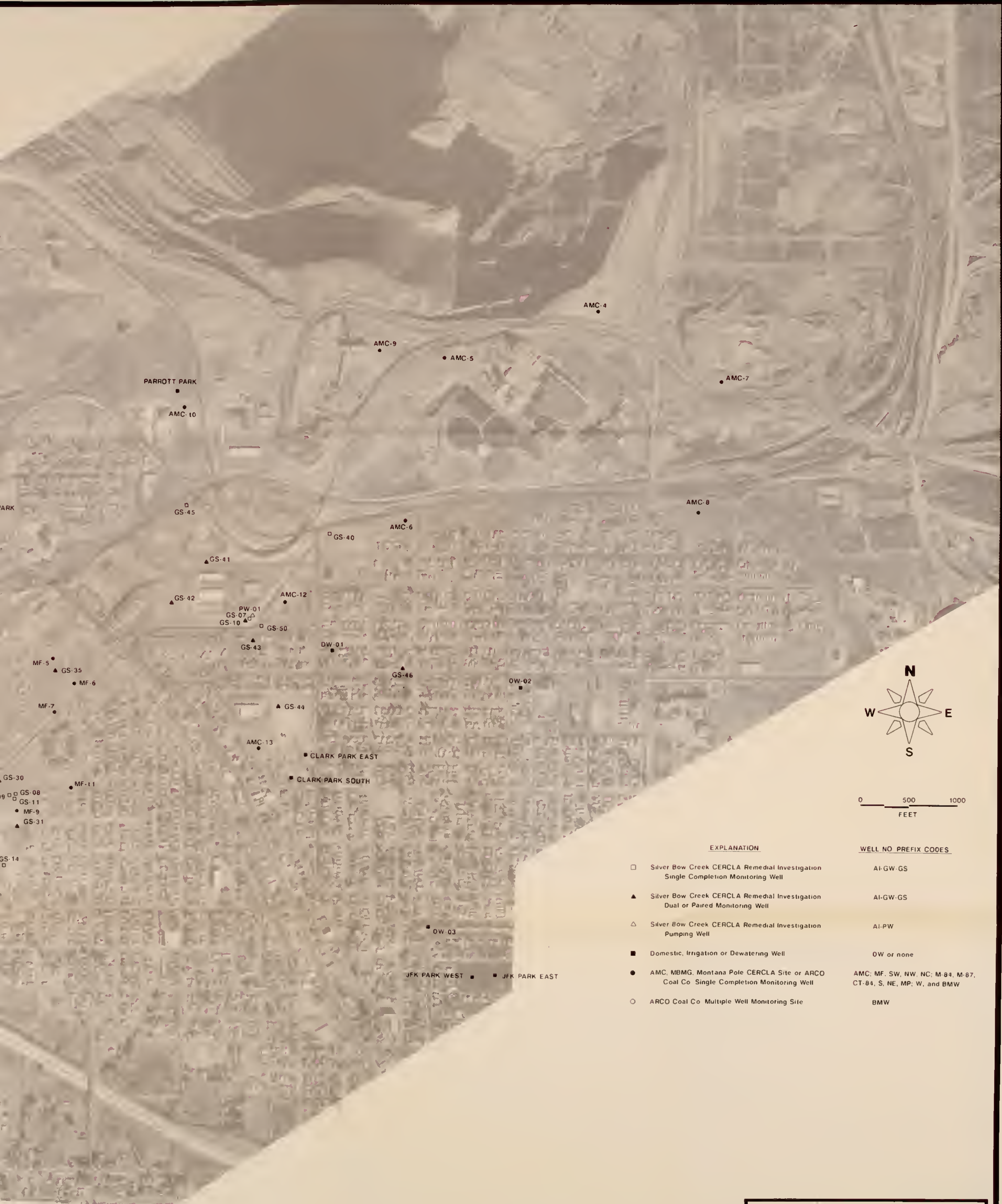

BMW-6
NW-3
NW-2
NW-4
NW-1
GS-27
GS-26
SW-3
BMW-4
SW-5
BMW-3
SW-1
SW-4
SW-2
BMW-2
N-1
BMW-11B
NE-2
NC-2
NE-1
NC-1
CT-84-9
PW-04
CT-84-8
CT 84-10
DW-128
S-5
GS-23
BMW-5
S-2
CT-84-5
CT-84-6
GS-25
DW-132
GS-24
BMW-13B
GS-34
S-3
S-4
BMW-1
GS-22
S-1
CT-1
GS-20
BMW-8
GS-16
PW-03
GS-12
GS-19
BMW-7
CT-84-2
CT-84-3
GS-17
BMW-12A
GS-21
BMW-9
BMW 10
GS-18
M-87-1
M-87-2
MP 5
W-3
W-6
M-87-6,7
M-87-3
MP-6
W-1
MP-4
MP-7
W-2
W-4
M-87-4
M-87-5
MP-1
W 10
W-7
W-8
W 11
W-9
W-12
W-14
W-13
W-15
W-17
W-16
MP-3
GS-13A
DW-131
GS-15
GS-29
MF-1
MF-4
MF-3
AMC-23
MF-2
AMC-24
GS-28
DW 120



EXPLANATION	WELL NO PREFIX CODES
□ Silver Bow Creek CERCLA Remedial Investigation Single Completion Monitoring Well	AI-GW-GS
▲ Silver Bow Creek CERCLA Remedial Investigation Dual or Paired Monitoring Well	AI-GW-GS
△ Silver Bow Creek CERCLA Remedial Investigation Pumping Well	AI-PW
■ Domestic, Irrigation or Dewatering Well	OW or none
● AMC, MBMG, Montana Pole CERCLA Site or ARCO Coal Co Single Completion Monitoring Well	AMC; MF, SW, NW, NC; M-84, M-87, CT-84, S, NE, MP; W, and BMW
○ ARCO Coal Co Multiple Well Monitoring Site	BMW

CH2M HILL

GROUNDWATER FEATURES MAP

Area I Operable Unit Phase II Remedial Investigation

NO	DATE	REVISION

DATE 2-9-90

EXHIBIT I

MONTANA STREET
INTERSTATE 90/15
FRONT
KAW
AVENUE
SBC
6AP
6A
6AC
6A-D
6D/7
6DP
6A-C
6B
6B-C
6C
6C/2
1-6C/2
6D-C
6A-E
6E
7/6A
6A/7
6A/4
4/8B
6AP/7
6AP/?
6D/4
6D
8C

FRONT STREET
KAW AVENUE
HARRISON AVENUE
MONTANA STREET
6A-E/2
6AP
6A
6AP/2
6A/2
6A-EP
6AP/7
4 (exposed)
6A/4
6A-D
4/8B
6AP/?
6D/4
8C
6D
MSD(4)
MSD
N
W
E
S
0 500 1000
FEET
1. Exposed Tailings
2. Covered Tailings
3. Manganese Flue Dust
4. Fluvial Alluvium/Tailings
5. Railroad Roadbed Fill
6. Cover and Fill Material
6A. Sand/gravel, roadfill, colluvium, mixed soil/fill
6B. Manganese Ore Piles (includes sandy manganese waste)
6C. Slag - includes both walls and scattered slag
6D. Demolition debris/Landfill material including cover
6E. Waste rock
7. Native Soil/Sediment - Exposed
8. Native Soil/Sediment - Covered
8A. Organic silt, clay, peat
8B. Sand gravel silt upper 2 feet
8C. Sand gravel silt lower than 2 feet
P Paved (6AP)
6A/2 Fill material over tailings
6A-E Mixed material, undifferentiated
Approximate Boundary
CH2M HILL
CONTAMINATED SOILS/TAILINGS DEPOSITS
Area I Operable Unit Phase II Remedial Investigation
NO DATE REVISION
DES EG
DR MP
CHK EG
APPD MG
SHEET
OF
DATE 2-9-90
EXHIBIT II